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METHODS AND CALCULATIONS IN HYGIENE AND VITAL STATISTICS

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IN

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METHODS AND CALCULATIONS

IN

HYGIENE AND VITAL STATISTICS

INCLUDING THE USE OF LOGARITHMS AND LOGARITHMIC TABLES

WITH EXAMPLES FULLY WORKED OUT

BY

HERBERT W. G. MACLEOD.

M.D., M.S. EDINBURGH ; D.P.H. CAMBRIDGE ; D.P.H. LONDON

First Class Honours in Public Health; Gold Medal, Senior, and Classical Scholarships in Arts; Fellow of the Incorporated Society of Medical Officers of Health; Member of the Sanitary Institute; Late Medical Officer of Health and Captain H.M.'s I.M.S.; Assistant to the Medical Officer of Health of the County of Essex and the Lecturer on Public Health, London Hospital; Demonstrator State Medicine Laboratories, King's College, London, &c. &c.

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PREFACE

In the following pages the most important Calculations and Formulæ connected with Hygiene and Vital Statistics are explained, and are illustrated by numerous Examples fully worked out.

An explanation is also given of Logarithms and Logarithmic Tables and of their use.

The methods usually adopted are shortly described, so that the Calculations which follow may more readily be understood.

In the Analysis of Foods, &c., details of laboratory *technique* are omitted, as being outside the scope of the book.

The Examples are taken chiefly from records of practical work, and some from Examination-papers.

Medical men and others working at Public Health, find it inconvenient to consult several books on Mathematics, Chemistry, &c., for Calculations which it is necessary for them to know, and the details of which are not given in standard Text-books on Hygiene. To them in particular I hope these pages will be found useful.

Work done in various Laboratories—at Netley (honoured by the names of Parkes and de Chaumont); King's College, London; the Jenner Institute; the University of Edinburgh; &c., and experience gained in teaching Hygiene, and as a Medical Officer

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of Health, have acquainted me with the requirements of Candidates for Qualifications in Public Health.

My thanks are due to Mr. G. Maxwell Lawford, M.Inst.C.E., for his Formulæ; to Mr. J. E. Mackenzie, D.Sc., Ph.D., for kindly revising some of the proof-sheets; and to Dr. Glaisher, of Cambridge, for permission to reproduce the Table of Glaisher's Factors.

I am obliged to Messrs. Baird & Tatlock, Casella & Co., A. Gallencamp & Co., J. J. Griffin & Sons, Mr. J. J. Hicks, Messrs. Negretti & Zambra, and Townson & Mercer, for blocks specially made, or lent, for illustrating the text.

HERBERT W. G. MACLEOD.

November 1903

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CORRIGENDA.

Page 25, line 1, *for* Hygrometers *read* Hydrometers.

,, 51, footnote, *for* 0.3 per cent. *read* 0.03 per cent.

,, 52, line 4 *et seq.* *for* $\frac{1200}{\frac{48}{144}} = 4000$ to end of (1).

read $\frac{12000}{\frac{48}{144}} = 36000 \quad \frac{36000}{60} = 600 \quad \frac{600}{60} = 10$

$$10 - \frac{10}{4} = 7.5 \text{ feet per second.}$$

,, 59, line 19, *for* A = 11.25 square inches *read* A = 20 square inches.

,, 61, ,, 6, *for* greater than *read* less than.

,, 91, last line, *for* $+\frac{1000}{4f} = 1$ *read* $\therefore \frac{1000}{4f} = 1$.

,, 82, lines 10 and 11, for x = 666,468 cubic feet × 6.25 = 4,165,425 gallons *read*: x = 170,615,808 cubic feet × 6.25 = 1066348800 gallons.

,, 95, line 6, *for* 1 c.c. = 0.1 grm. Pb *read* 1 c.c. = 0.1 mgr. Pb.

,, ,, ,, 7 from bottom, *for* 1 c.c. = 1 mgr. Pb *read* 1 c.c. = 0.1 mgr. Pb.

,, ,, ,, 12, *for* 1 c.c. = 0.1 grm. Cu *read* 1 c.c. = 0.1 mgr. Cu.

,, 103, Fig. 24 (Note), *for* radii of the sides is 1.50 *read* are 1.50.

,, 107, line 5, *for* 1.3 *read* 1.2.

,, 113, ,, 21, *for* in 100 c.c. *read* in 10 c.c.

,, 115, ,, 10, *for* total solids *read* non-fatty solids.

,, ,, ,, 15, *for* 7 : 6 *read* 0.7 : 0.6.

,, 126, last line, *for* $\overline{7} + \overline{6} = 1$ *read* $7 + \overline{6} = 1$.

,, 135, line 3, *omit* (or crude death-rate).

,, ,, ,, 8 from bottom, *omit* (crude).

,, ,, ,, 11 ,, ,, ,, (*i.e.*, the *crude death-rate*).

,, 136, ,, 14 ,, ,, *for* notified cases *read* notified deaths.

,, 143, *for* $\sqrt{\frac{3808}{1000}}$ *read* $\sqrt{\frac{9248}{1000}}$

CHAPTER X

Logarithms and Logarithmic Tables

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METHODS AND CALCULATIONS IN HYGIENE AND VITAL STATISTICS

CHAPTER I.

CHEMISTRY.

To Determine the true Position of Equilibrium in a Chemical Balance.—Raise the beam and free the pans by turning the handle. If the oscillations of the pointer are of equal length to the right and left of the scale the instrument is correct. If of unequal lengths, correct as follows by taking an *unequal* number of readings (say 3), commencing with the first swing of the index.

Oscillations of the pointer to the right of the zero are written + ; those to the left − .

EXAMPLE.

(1)

		+			−
3 Oscillations	1st to right	8.6	2 Oscillations	1st to left	5.3
	2nd „	7.8		2nd „	4.5
	3rd „	6.2			9.8
		22.6			

$$\frac{22.6}{3} = +7.5 \qquad \frac{9.8}{2} = -4.9$$

$$7.5 - 4.9 = +2.6$$

The balance points 2.6 in excess to the *right*.

$$\therefore \frac{2.6}{2} = 1.3 \text{ to the right is the zero-point.}$$

(2)

		+			−
2 Oscillations	1st to right	4.3	3 Oscillations	1st to left	7.2
	2nd „	3.2		2nd „	6 3
		7.5		3rd „	5.5
					19.0

$$\frac{7.5}{2} = \overset{+}{3.8} \qquad \frac{19}{3} = \overset{-}{6.3}$$

Difference = 2.5 to the *left* in excess.

$$\therefore \frac{2.5}{2} = 1.2 \text{ to the left is the zero-point.}$$

Temperature Scales.

The three scales in use are (1) the Centigrade or Celsius—universally used for scientific work; (2) the Fahrenheit, adopted in Great Britain for Meteorological observations and largely used in Hygiene; (3) the Réaumur, which is used in Russia chiefly, and may be neglected.

The Centigrade and Réaumur scales have the zero-point at the temperature of melting ice or freezing water. Fahrenheit, by using a mixture of ice and salt to determine his zero temperature, obtained it 32 of his degrees below the melting-point of ice. This is therefore marked 32° F. and coincides with 0° C. and 0° R.

The boiling-point of water is 100° C., 212° F., and 80° R., the respective scales being divided between the freezing- and boiling-points into 100, 180, and 80 equal divisions.

As Fahrenheit's freezing-point is 32°, and 180 divisions separate this from the boiling-point, the latter equals 32 + 180 = 212°.

Therefore $$\frac{C}{100} = \frac{F - 32}{212 - 32} = \frac{R}{80}$$

$$\therefore \frac{C}{10} = \frac{F - 32}{18} = \frac{R}{8}$$

or $$\frac{C}{5} = \frac{F - 32}{9} = \frac{R}{4}$$

Example.

Convert into Fahrenheit degrees:

(1) 68.3° C. $\quad \frac{68.3}{5} = \frac{F - 32}{9}$ $\quad 9 \times 68.3 = 5(F - 32)$

$614.7 = 5F - 160$

$614.7 + 160 = 5F$

$F = 154.94°$.

(2) −40° C. $\quad \frac{-40}{5} = \frac{F - 32}{9}$

$-8 = \frac{F - 32}{9}$ $\quad -72 = F - 32$

$F = -72 + 32$

$F = -40$

−40° C. and −40° F. correspond in both scales, and closely approximate to the freezing-point of mercury.

(3) -27° C. $\quad \frac{-27}{5} = \frac{F-32}{9}$ $\quad 5F - 160 = -243$, $\quad 5F = -83$, $\quad F = -16.6^\circ$

Convert into Centigrade degrees:

(1) 31° F. $\quad \frac{31-32}{9} = \frac{C}{5}$ $\quad \therefore \frac{-1}{9} = \frac{C}{5}$. $\quad -5 = 9C$

$$C = \frac{-5}{9} = -0.\dot{5}^\circ \text{ (recurring decimal)}$$

(2) 0° F. $\quad \frac{0-32}{9} = \frac{C}{5}$

$\frac{-32}{9} = \frac{C}{5}$. $\quad 9C = -160$, $\quad C = -17.7^\circ$

(3) -19° F. $\quad \frac{-19-32}{9} = \frac{C}{5}$. $\quad \frac{-51}{9} = \frac{C}{5}$ $\quad 9C = -255$, $\quad C = -28.3^\circ$

Density.

Mass is the amount of matter a body contains.

Weight expresses the force with which the mass of a body is attracted to the earth by gravitation, and represents the mass of the body weighed.

Mass is an invariable quantity, but weight varies with the force of attraction and differs with the latitude of a place. For convenience the mass of a body is expressed in terms of weight.

Density is "absolute" and "relative."

Absolute density is the mass of unit volume of a substance, and is estimated by weighing a measured volume.

Relative density is the ratio of the mass of any volume of a substance to the mass of an equal volume of another substance taken as a standard. The standard usually taken for solids and liquids is pure distilled water at 4° C. or 39° F.—its temperature of maximum density, and the density *of any substance relative to water* is its *specific gravity*. In other words, its weight in air divided by the weight of an equal volume of water at 4° C. or 39° F. expresses its specific gravity.

In Hygiene and Physics air is used as the standard for gases instead of water, and the temperature 15.5° C. or 60° F. is usually adopted for convenience, that being the degree of warmth commonly met with in laboratories. It may be denoted *standard laboratory temperature*, and the pressure of 760 mm. of mercury or 30 in. is taken as the standard or normal pressure.

"*Normal* temperature and pressure," written "N.T.P.," means 0° C. or 32° F., and 760 mm. or 30 inches.

The mass of a body is directly proportional to its density and volume: Absolute density × Volume = Mass.

$$\therefore \text{ Absolute density} = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Weight (expressing mass)}}{\text{Volume}}$$

A gravimetric or quantitative analysis by weight estimates the weight of the various substances a body contains.

A volumetric or quantitative analysis by volume determines their respective volumes and is applicable to liquids and gases. From the known volumes the weights can be calculated by the laws of chemical equivalence.

In the metric system the unit of weight or mass is the *gramme* and the unit of volume for solids and liquids is the *cubic centimetre*, and for gases and vapours the *litre* or *cubic decimetre*.

The British units of weight and volume are the *pound* and *grain*, and the *cubic foot* or *cubic inch*.

The gramme is (very nearly) the weight of 1 c.c. of distilled water at 4° C. and 760 mm. pressure. This system has the advantage of expressing weight and measure at the same time, so that 1 c.c. represents the corresponding weight of water in grammes, and the weight of 1 c.c. indicates both the density and specific gravity of any substance. At temperatures of 15.5° C. or 60° F., instead of at 4° C., the difference in weight is so insignificant that the error may be neglected, except in very accurate estimations.

In the British system the pound and cubic foot have not the convenient relation between the mass and bulk of water as in the French system—now almost universal in scientific work. The British units of mass and volume give different numbers expressing density and specific gravity, and are not directly convertible.

In chemical calculations the unit of weight for gases and vapours is the weight of a litre of dry hydrogen at 0° C. and 760 mm. (32° F. and 30 in.). This is 0.08958, or shortly 0.0896 gramme. The weight of 1 c.c. of hydrogen is therefore $\frac{1}{1000}$ of this, and is equal to 0.0000896 gramme, "N.T.P."

The cubic centimetre is too small a unit for estimating the volume of gases, and weight per litre has the disadvantage of expressing density in fractional parts of a gramme. 11.16 litres are therefore used as the unit of volume for vapours and gases and the densities are expressed as whole numbers.

The absolute density of a gas is the mass of 11.16 litres at N.T.P. By Avogadro's law: "The molecular weight in grammes of any gas at 0° and 760 mm. occupies a volume of 22.32 litres."

One litre of hydrogen under normal conditions weighs 0.0896

gramme, therefore by the following equation we find the volume of 1 gramme of hydrogen (N.T.P.) is 11.16 litres:

$$0.0896 : 1 :: 1 : x. \quad x = \frac{1}{0.0896} = 11.16$$

and that of 2 grammes of hydrogen (N.T.P.) is 22.32 litres.

$$0.0896 : 2 :: 1 : x.$$
$$x = 22.32 \text{ litres.}$$

The latter is known as the "gramme-molecular volume of hydrogen," as it expresses the volume of its molecular weight in grammes.

"Equal volumes of gases at the same temperature and pressure contain the same number of molecules, and the masses or weights of their molecules are in the same ratio as the densities of the gases to which they belong" (Avogadro).

Therefore under *normal* conditions:

22.32 litres of hydrogen weigh 2 grammes.
22.32 „ oxygen weigh $16 \times 2 = 32$ grammes.
22.32 „ carbon dioxide weigh $22 \times 2 = 44$ grammes.

Therefore, if the *molecular* weight of any *element* or *compound* is x, 22.32 litres of it will weigh x grammes.

The density of nearly all elements in the state of gas or vapour corresponds to their atomic weights. Taking hydrogen as 1, the vapour-density of oxygen is $\frac{32}{2}$ or 16, and that of CO_2 is $\frac{44}{2} = 22$.

The density of any gas, simple or compound, is half its molecular weight. The weight of 1 litre of hydrogen under N.T.P. is 0.0896 gramme, and the weight of 1 litre of nitrogen under similar conditions is 0.0896×14 (the atomic weight of nitrogen) or 1.25 grammes. The weight of 1 litre of oxygen is $0.0896 \times 16 = 1.43$ grammes. 1 litre of aqueous vapour weighs $\frac{18}{2} \times 0.0896 = 0.806$ gramme, and 1 litre of $CO_2 = \frac{44}{2} \times 0.0896 = 1.97$ grammes. Air is 14.44 times heavier than hydrogen.

Air contains *approximately* 21 per cent. of O and 79 per cent. N by volume.

O. $21 \times 16 = 336$
N. $79 \times 14 = 1106$ } 1442 grammes per 100 volumes of air.
$100 \times 1 = 100$ grammes per 100 volumes of hydrogen.

$\therefore$ 1 volume of air = 14.42, 1 volume of H = 1; *i.e.*, air is 14.4 times heavier,

and 1 litre of dry air under standard conditions weighs $0.0896 \times 14.44 = 1.293$ grammes (*vide* p. 4). If the weight of air is

taken as the unit (as in Meteorology and Physics), the relative weight or specific gravity of an equal volume of hydrogen is 14.44 times less than 1, and is equal to $\frac{1}{14.44} = 0.0693$.

If the density of two gases or vapours relative to hydrogen is known, the ratio between them can be calculated at once.

Thus, the density of CO_2 to hydrogen is $\frac{44}{2}$ or 22, and that of air is 14.44; therefore,

density of CO_2 : density of air : : 22 : 14.44, or as $\frac{22}{14.44} = 1.52$.

Similarly the vapour density of water relative to air is first expressed in "terms of hydrogen" and the ratio is then made; this is $\frac{9}{14.44} = 0.623$.

The molecular weight of a compound is the total weight of the atoms in a molecule of it. It is calculated from the chemical formula by multiplying the atomic weight of each element in it by the number of atoms of that element and adding these numbers together.

Example.—Nitric anhydride is represented by N_2O_5. The atomic weight of N = 14, O = 16, and there are in the compound 2 and 5 atoms of each. Therefore $14 \times 2 + 16 \times 5 = 28 + 80 = 108$, which is the molecular weight.

Sulphuric acid = H_2SO_4.

$\therefore 1 \times 2 + 32 + 16 \times 4 = 98$, is the molecular weight.

Sodium sulphate = $Na_2SO_4.10H_2O$. Its molecular weight is: $23 \times 2 + 32 + 16 \times 4 + 10 \times 18 = 322$.

Oxalic acid: $C_2H_2O_4.2H_2O$: $12 \times 2 + 1 \times 2 + 16 \times 4 + 18 \times 2 = 126$. These parts by weight may be "grammes," "pounds" or "grains."

The percentage composition of each element is found by simple proportion from the molecular weight:

Taking nitric anhydride:

The percentage amount of nitrogen and oxygen it contains is calculated thus:

108 : 100 : : 28 : x. $\quad x = \frac{2800}{108} = 25.9$ nearly.

108 : 100 : : 80 : x. $\quad x = 74.1$ approximately.

And $25.9 + 74.1 = 100$.

Oxalic acid: C = 19.0 per cent.
H = 4.8 ,,
O = 76.2 ,,

100.0 (grammes or grains).

A chemical equation expresses the results of chemical action and indicates the parts by weight of the molecule or molecules of each substance employed in the reaction.

The weights may be of any system, but must be of the same nature throughout the equation.

Atoms do not exist as such in the free state, but are in combination to form one or more molecules. Mercury is an exception, its molecule consists of one atom only.

Thus:

$$\underset{\substack{(1\text{ molecule}=64\\ \text{parts by weight})}}{SO_2} + \underset{\substack{(1\text{ molecule}=254\\ \text{parts by weight})}}{I_2} + \underset{\substack{(2\text{ molecules}=\\ 36\text{ parts})}}{2H_2O} = \underset{\substack{(1\text{ molecule}=\\ 98\text{ parts})}}{H_2SO_4} + \underset{\substack{(2\text{ molecules}=\\ 256\text{ parts})}}{2HI}.$$

If 10 grains of H_2SO_4 are required, how many grains of SO_2 and I_2 would be needed?

$$98 : 10 :: 64 : x. \qquad x = \frac{640}{98} = 6\ 53 \text{ grains (nearly) of } SO_2.$$

$$98 : 10 :: 254 : x. \qquad x = \frac{2540}{98} = 26 \text{ grains (nearly) of iodine.}$$

$$\underset{(2\text{ molecules}=432)}{2HgO} = \underset{(1\text{ molecule}=400)}{2Hg} + \underset{(1\text{ molecule}=32)}{O_2}$$

How much oxygen will 5 grammes of HgO yield?

$$\therefore\ 432 : 5 :: 32 : x. \qquad x = 0.37 \text{ gramme of oxygen.}$$

In calculations of the volumes of gas formed by chemical combination the relations between molecular weight and volume of the respective gases must be known. One *molecule* of a gas under N.T.P. occupies the same volume as one molecule or two atoms of hydrogen—*i.e.*, 1 volume or 22.32 litres, which is the gramme-molecular volume expressing both weight and volume.

The volume of the gas in the last example is easily calculated from the equation: the gramme-molecular volume O_2 at N.T.P. is 22.32 litres, and 432 grammes of HgO yield that volume as per equation.

Therefore: $432 : 5 :: 22.32 : x.$ $\quad x = \frac{111.6}{432} = 0.258$ litre of oxygen.

The molecule of a gas occupies 1 volume at 0° C. and 760 mm. and each gramme-molecule is 22.32 litres, but the volume alters with change of temperature.

Changes of Volume and Temperature, Pressure remaining the same.—By Charles' or Gay-Lussac's law the volume of gas *at constant pressure* expands or contracts $\frac{1}{273}(=0.003665)$ of its volume at 0° C. for each increase or decrease of 1° C.

In the Fahrenheit scale gases at 32° F. increase or diminish

$\frac{1}{491}$ (0.002) of their volume for every rise or fall of 1° F., the *pressure remaining the same.* These fractions are "coefficients of expansion" of gases in the respective scales.

In other words:

At 0° C. 273 volumes of a gas under constant pressure become:
„ 1° C. = 273 + 1 volumes, and at − 1° C. = 273 − 1 volumes.
„ 2° C. = 273 + 2 „ „ − 2° C. = 273 − 2 „
„ T° C. = 273 + T „ „ − T° C. = 273 − T „

Similarly at 32° F. 491 volumes of gas under constant pressure become:

at 33° F. = 491 + 1 volumes, and at 31° F. = 491 − 1 volumes.
„ 34° F. = 491 + 2 „ „ 30° F. = 491 − 2 „
„ 32 + T° = 491 + T „ „ 32 − T° = 491 − T „

As the volumes of all gases vary directly with absolute temperature (the zeros being − 273° C. and − 491° F.), 273 or 491 must be added to all observed or required temperatures in making calculations and corrections for changes of volume so as to express them as degrees on the "absolute scale." Thus, 15° C. becomes 273 + 15, and − 15 C. = 273 − 15. 62° F. = 491 + 62, and − 20° F. = 491 − 20.

The formula for the Centigrade scale is $\frac{V_1}{V_2} = \frac{273 + T_1}{273 + T_2}$, where T_1 and V_1 represent the original temperature and volume and T_2 and V_2 the temperature and volume for which the calculation or correction is made.

Example.—What will be the volume at − 10° C. of 120 c.c. of a gas measured at 15° C.? Here $V_1 = 120$. $T_1 = 15$, $T_2 = -10$. V_2 is to be calculated.

$$\frac{120}{V_2} = \frac{273 + 15}{273 + (-10)}. \qquad V_2 = \frac{120(273 - 10)}{273 + 15} = 109.58 \text{ c.c.}$$

(2) 15 c.c. of CO_2 are measured at 12° C. What would the volume be at 36° C.?

$$\frac{15}{V_2} = \frac{273 + 12}{273 + 36} \qquad V_2 = 16.26 \text{ c.c.}$$

In Fahrenheit's scale the formula is $\frac{V_1}{V_2} = \frac{491 + (T_1 - 32)}{491 + (T_2 - 32)}$

or by deducting 32° from 491 at once: $\frac{V_1}{V_2} = \frac{459 + T_1}{459 + T_2}$

$$\therefore\ V_2 = \frac{(459 + T_2) \times V_1}{459 + T_1}$$

Example.—What volume will 128 cub. in. of nitrogen measured at 32° F. occupy at 122° F. (constant pressure)?

$$\frac{128}{V_2} = \frac{459 + 32}{459 + 122} = 151.4 \text{ cubic inches.}$$

To Correct the Volume of a Gas for Normal Temperature.

Let V_1 = observed volume of the gas
T_1 = observed temperature of the gas. $T = 0°$ C.

$\therefore\ V_2$ = volume at 0° C.

$$\therefore\ \frac{V_1}{V_2} = \frac{273 + T_1}{273 + 0}$$

$$V(273 + T_1) = 273 \times V_1 \qquad \therefore\ V_2 = \frac{273 \times V_1}{273 + T_1}$$

Example.—Find the volume which 147.8 c.c. of a gas originally measured at 50° C. will occupy when the temperature falls to 0° C.

$$V_2 = \frac{273 \times 147.8}{273 + 50} = 124.9 \text{ c.c.}$$

Fahrenheit scale: $\frac{V_1}{V_2} = \frac{491 + (T_1 - 32)}{491 + (T_2 - 32)}$, but $T_2 = 32$

$$\therefore\ \frac{V_1}{V_2} = \frac{491 + (T_1 - 32)}{491 + 0} = \frac{459 + T_1}{491}$$

$$V_2 = \frac{491 \times V_1}{459 + T_1}$$

Example.—Calculate the volume which 147.8 cubic inches of a gas measured at 122° F. will occupy at normal temperature, pressure remaining unaltered.

$T_2 = 32°$ F. $\quad V_2 = \frac{491 \times 147.8}{491 + (122 - 32)} = \frac{491 \times 147.8}{459 + 122} = 124.9$ cb. in.

The density of a gas varies inversely as the *absolute* temperature if pressure remains unaltered.

Let D_1 and D_2 be the densities at temperatures T_1 and T_2.

$$\therefore\ \frac{D_1}{D_2} = \frac{273 + T_2}{273 + T_1}.$$

Example.—At what temperature will air having a density of 14.44 (relative to hydrogen as 1) be of the same density as oxygen at 0° C. or 32° F., pressure being constant?

T_2 is to be found.

$$\frac{14.44}{16} = \frac{273 + T_2}{273 + T_1} = \frac{273 + T_2}{273 + 0}.$$

$$16(273 + T_2) = 14.44 \times 273.$$

$$T_2 = -26.6^\circ \text{ C.}$$

In the Fahrenheit scale:

$$\frac{14.44}{16} = \frac{491 + (T_2 - 32)}{491 + (T_1 - 32)} = \frac{459 + T_2}{459 + T_1} = \frac{459 + T_2}{459 + 32}.$$

$$\therefore\ 16(459 + T_2) = 14.44 \times 491.$$

$$T_2 = -15.87^\circ \text{ F.}$$

Changes of Volume and Pressure, Temperature remaining the same.—By Boyle's and Mariotte's law the volume of a gas varies inversely as the pressure, temperature remaining constant.

The formula is $\frac{V_1}{V_2} = \frac{P_2}{P_1}$.

EXAMPLE.—237 litres of a gas are measured at 755 mm. pressure. Find the volume if the pressure be changed to 915 mm., the temperature being unaltered.

$V_1 = 237$ litres. V_2 is to be found.
$P_2 = 915$. $P_1 = 755$.

$$\therefore \frac{237}{V_2} = \frac{915}{755}. \quad V_2 = \frac{237 \times 755}{915} = 195.5 \text{ litres.}$$

To Correct the Volume of a Gas for Normal Pressure.

Let V_1 = observed volume.
P_1 = observed pressure (height of barometer in mm.).
$V_2 = V_n$ = volume at *normal* pressure (760 mm.).
$P_2 = 760$ m.m.

$$\therefore \frac{V_1}{V_n} = \frac{P_2}{P_1}. \quad \therefore V_n = \frac{V_1 \times P_1}{P_2} = \frac{V_1 \times P_1}{760}.$$

EXAMPLE.—Correct for normal pressure the volume of 1 litre of a gas measured at 740 mm. pressure, temperature being unaltered.

1 litre = 1000 c.c. P_n = normal pressure = 760 mm.

$$\therefore \frac{1000}{V_n} = \frac{760}{740}. \quad V_n = \frac{1000 \times 740}{760} = 973.6 \text{ c.c.}$$

In the Fahrenheit scale:

Let $V_1 = 1000$ cubic inches.
$V_2 = V_n$ = volume at normal pressure.
$P_1 = 29.2$ inches.
$P_2 = 30$ inches.

$$\therefore \frac{1000}{V_n} = \frac{30}{29.2}.$$

$$V_n = \frac{1000 \times 29.2}{30} = 973.3 \text{ cubic inches.}$$

Under constant Temperature Density varies directly as Pressure.—The ratio is expressed thus: $\frac{D_1}{D_2} = \frac{P_1}{P_2}$.

We have already seen that density varies inversely as the *absolute* temperature if pressure is constant, the ratio being:

$$\frac{D_1}{D_2} = \frac{273 + T_2}{273 + T_1}.$$

Example.—The density of air at 760 mm. pressure is 14.44, at what pressure will it equal that of normal oxygen?

$D_1 = 14.44$. $D_2 = 16$. $P_1 = 760$. P_2 is to be calculated.

$$\therefore \frac{14.44}{16} = \frac{760}{P_2}.$$

$$P_2 = \frac{16 \times 760}{14.44} = 842.1 \text{ mm.}$$

Expressing pressure in inches of mercury instead of as millimetres, the same example becomes:

$$\frac{14.44}{16} = \frac{30}{P_2}. \quad P_2 = 33.2 \text{ inches.}$$

By Boyle's and Mariotte's law: $\frac{V_1}{V_2} = \frac{P_2}{P_1}$ (p. 10), and as density varies directly as pressure $\frac{P_2}{P_1} = \frac{D_2}{D_1}$, therefore $\frac{V_1}{V_2} = \frac{P_2}{P_1} = \frac{D_2}{D_1}$, *i.e.*, temperature remaining constant, volume varies inversely as density, and *vice versâ* density varies inversely as volume.

Example.—250.4 volumes of nitrogen have a density of 14. Find the volume when the pressure is diminished and the density becomes 12.

$V_1 = 250.4$ $\quad$ $D_1 = 14$
V_2 is to be found. $\quad$ $D_2 = 12$.

$$\frac{250.4}{V_2}=\frac{12}{14}. \quad V_2=\frac{250.4\times 14}{12}=292.1 \text{ volumes.}$$

Change of Volume with simultaneous Changes of Temperature and Pressure.—The formulæ of Charles' and Boyle's laws are used together thus:

(1) $$\frac{V_1}{V_2}=\frac{273+T_1}{273+T_2}. \quad \text{Or: } V_1 : V_2 :: (273+T_1) : (273+T_2).$$

(2) $$\frac{V_1}{V_2}=\frac{P_2}{P_1}. \quad \text{Or: } V_1 : V_2 :: P_2 : P_1.$$

Combining these two formulæ for correcting the volume for temperature and pressure simultaneously:

$$\frac{V_1}{V_2}=\frac{(273+T_1)}{(273+T_2)}\times\frac{P_2}{P_1}. \quad \text{Or: } V_1 : V_2 :: (273+T_1)\times P_2 : (273+T_2)\times P_1$$

$$\therefore\ V_2=V_1\times\frac{(273+T_2)}{(273+T_1)}\times\frac{P_1}{P_2}.$$

In the Fahrenheit scale: $$\frac{V_1}{V_2}=\frac{491+(T_1-32)}{491+(T_2-32)}\times\frac{P_2}{P_1}$$

$$=\frac{(459+T_1)\times P_2}{(459+T_2)\times P_1}$$

$$\therefore\ V_2=V_1\times\frac{(459+T_2)}{(459+T_1)}\times\frac{P_1}{P_2}.$$

Example.—250 litres of a gas are measured at 745 mm. pressure and 15° C. Calculate the volume at 25° C. and 765 mm. pressure.

(1) By Charles' law: $$\frac{250}{V_2}=\frac{273+15}{273+25}.$$

(2) By Boyle's law: $$\frac{250}{V_2}=\frac{765}{745}.$$

$$\therefore\ \frac{250}{V_2}=\frac{(273+15)}{(273+25)}\times\frac{765}{745}. \quad V_2=\frac{250\times(273+25)}{(273+15)}\times\frac{745}{765}$$

$$=251.9 \text{ litres.}$$

Example.—250 cubic inches of dry air are measured at 29.4 inches and 5° F. Find what the volume would be at 30.2 inches and 77° F.

$$\frac{250}{V_2}=\frac{(459+5)}{(459+77)}\times\frac{30.2}{29.4}. \quad V_2=\frac{250\times(459+77)}{(459+5)}\times\frac{29.4}{30.2}=281.1 \text{ c.in.}$$

To Correct for Normal Temperature and Pressure simultaneously.—The above formulæ are only modified.

Let $V_2 = V$ = volume at N.T.P.

$T_2 = 0^\circ$ C., or 32° F.

and $273 + T_2 = 273 + 0^\circ$ C.

and $459 + T_2 = 459 + 32^\circ$ F. $= 491$.

$P_2 = P_n = 760$ mm. (C.°), or 30 inches (F.°).

$$\therefore \frac{V_1}{V_n} = \frac{(273 + T_1)}{(273 + 0)} \times \frac{760}{P_1} \text{ for Centigrade.}$$

$$V_n = V_1 \times \frac{273}{273 + T_1} \times \frac{P_1}{760}.$$

For Fahrenheit: $\frac{V_1}{V_n} = \frac{(459 + T_1)}{(459 + 32)} \times \frac{30}{P_1} = \frac{(459 + T_1)}{491} \times \frac{30}{P_1}$.

$$V_n = V_1 \times \frac{491}{459 + T_1} \times \frac{P_1}{30}.$$

Example.—Find the volume which 500 c.c. of a dry gas or vapour measured at 15° C. and 750 mm. pressure will occupy at normal temperature and pressure.

$$\frac{500}{V_n} = \frac{(273 + 15)}{(273 + 0)} \times \frac{760}{750}$$

$$V_n = \frac{500 \times 273}{288} \times \frac{750}{760} = 467.7 \text{ c.c.}$$

The same example converted into the Fahrenheit scale of temperature and inches of pressure, and taking the original volume as equal to 500 cubic inches, gives:

15° C. $= 59^\circ$ F. and 750 mm. $= 29.6$ inches.

$$\therefore \frac{500}{V_n} = \frac{(459 + 59)}{(459 + 32)} \times \frac{30}{29.6}$$

$$V_n = \frac{500 \times 491}{518} \times \frac{29.6}{30} = 467.6 \text{ cubic inches.}$$

Sometimes the Fahrenheit scale is used for temperature, and the metric system for pressure, so that the problem may be:

Find the volume under N.T.P. of 1 cubic foot of dry air measured at 60° F. and 730 mm. pressure.

Without converting 730 mm. into inches:

$$\frac{V_1}{1} = \frac{760}{730} \times \frac{(459 + 60)}{(459 + 32)} \quad \therefore \frac{1}{V_n} = \frac{760}{730} \times \frac{519}{491}.$$

$$V_n = \frac{730}{760} \times \frac{491 \times 1}{519} = 0.908 \text{ cubic foot.}$$

If the normal pressure is to be expressed as 30 inches and not as 760 mm., then 730 mm. must be converted into inches thus: 760 : 730 : : 30 : x.

$$x = 28.8.$$

$$\therefore V_n = \frac{28.8}{30} \times \frac{491 \times 1}{519} = 0.908 \text{ cubic foot (as before).}$$

To Find the Weight of a given Volume of Gas at a given Temperature and Pressure.

(1) Find the volume corrected for N.T.P.

Let W = required weight.

V_1 = original volume, V_2 = required volume.

P_1 = original pressure, P_2 = required pressure (normal).

T_1 = original temperature, T_2 = required temperature = 0° C.

Centigrade Scale:

$$V_2 = \frac{P_1}{760} \times \frac{273 \times V_1}{273 + T_1}$$

(2) Multiply the "corrected" volume by the weight of 1 litre (unit volume) at N.T.P.

Example.—Find the weight of 1 litre of dry air at 15° C. and 730 mm. pressure.

(1) $V_1 = 1$ litre. $V_2 = \frac{730}{760} \times \frac{273 \times 1}{(273 + 15)} = 0.91$ litre.

(2) 1 litre of dry air N.T.P. = 1.293 grammes:

1 : 0.91 : : 1.293 : $x = 0.91 \times 1.293 = 1.176$ grammes.

Fahrenheit Scale:

$$(1)\ V_2 = \frac{P_1}{30} \times \frac{491 \times V_1}{459 + T_1}.$$

(2) Multiply the result by the weight of 1 cubic foot (unit volume) at N.T.P.

Example.—Calculate the weight of 1 cubic foot of dry air at 75° F. and 29 inches pressure.

1 cubic foot of dry air at N.T.P. = 567 grains (approximately).

$$\therefore W = \frac{29}{30} \times \frac{491 \times 1}{534} \times 567 = 503.96 \text{ grains.}$$

Example.—Find the weight of 1 cubic foot of CO_2 at 62° F. and 28.5 inches pressure.

$$(1)\ V_2 = \frac{28.5}{30} \times \frac{(459+32)\times 1}{(459+62)} = 0.89 \text{ cubic foot, } CO_2.$$

(2) To express the weight of CO_2 in terms of dry air relative to hydrogen.

$$\frac{\text{Weight of 1 cubic foot, } CO_2}{\text{Weight of 1 cubic foot of dry air}} = \frac{22}{14.44} = 1.52.$$

∴ Weight of 1 cubic foot CO_2 = weight of 1 cubic foot of dry air × 1.52.

Weight of 1 cubic foot of dry air = 567 grains approximately.

∴ Weight of 1 cubic foot CO_2 = 567 × 1.52 grains.

∴ 0.89 cubic foot CO_2 = 0.89 × 567 × 1.52 = 767.0376 grains.

Mixture of Gases and Vapours.—By Dalton's law, if several gases or vapours are enclosed in the same space, each one exerts the same pressure as it would if the others were absent. This "partial pressure" is known as "vapour tension," "elastic force," or "force of expansion." The total pressure, or weight, of a mixture of gases and vapours is the sum of the partial pressures or weights. There is a limit to the quantity of vapour which can be formed at a given temperature, and both the vapour itself and the space containing it are said to be "saturated" when this limit is reached. The vapour is then at "maximum tension" and "maximum density." The vessel containing a mixture of gases has a uniform pressure at all points of its surface. The pressure of a vapour in contact with its own liquid is the same for the same temperature.

EXAMPLE.—100 volumes of pure dry air at a pressure of 760 mm. contain :

Oxygen	20.94	parts
Nitrogen	79.00	,,
Hydrogen	0.02	,,
Carbon dioxide	0.04	,,

Find the partial pressure of each.

Oxygen : 100 : 760 : : 20.94 : x. $\quad x = \frac{760 \times 20.94}{100} = 159.144$ mm.

Similarly Nitrogen $= \frac{760 \times 79}{100} = 600\ 4$ mm.

Hydrogen $= \frac{760 \times 0.02}{100} = 0.152$ mm.

$CO_2 = \frac{760 \times 0.04}{100} = 0.304$ mm.

If the gas contains moisture (*i.e.*, water vapour) and the volume is to be calculated under normal conditions: *

Let p = pressure of aqueous vapour
P = ,, ,, the moist gas (gas and vapour)
$\therefore P - p$ = ,, ,, ,, dry gas.

The formula is $V_2 = \frac{(P-p) \times 273 \times V}{760 \times (273 + T)}$. It corrects the volume of a gas for temperature, pressure, and aqueous vapour.

Example.—The observed volume of gas and water-vapour is 68.6 c.c., the height of the barometer is 738.5 mm. and the temperature is 15.0° C. Find the volume under normal conditions.

It is necessary in all cases to ascertain by Vapour-tension tables (*e.g.*, Regnault's) the maximum tension (*i.e.*, *pressure*) of the aqueous vapour present at this temperature.

It is found that this pressure at 15° C. = 12.7 mm. Hence we have: $V = 68.6$ c.c. $P = 738.5$ mm. $p = 12.7$ mm.

The true pressure of the dry gas is $738.5 - 12.7 = 725.8$ mm.

$$\therefore V_2 = \frac{725.8 \times 273 \times 68.6}{760 \times (273 + 15)} = 62.1 \text{ c.c.}$$

For the Fahrenheit scale the formula is:

$$V_2 = \frac{(P-p)}{30} \times \frac{491 \times V}{(459 + T)}.$$

Example.—Find the volume which 1 cubic foot of moist air at 60° F. and 29.5 inches pressure will occupy under N.T.P.

The maximum tension or pressure of aqueous vapour at 60° F. and 29.5 inches = 0.52 inch.

$$\therefore V_2 = \frac{(29.5 - 0.52) \times 491 \times 1}{30 \times (459 + 60)} = 0.914 \text{ cubic foot.}$$

Absorption of Gases in Liquids having no Chemical Action on them.—The volume of gas dissolved is constant for the same temperature at (approximately) all pressures; the weight of the dissolved gas is directly proportional to the pressure. (Dalton's and Henry's law.)

The ratio of the volume of gas dissolved to the unit volume of water (or any other liquid) which dissolves it is, under certain fixed conditions of temperature and pressure, a fixed and definite quantity, and is called the "coefficient of absorption" of the body for that particular gas.

The coefficient of absorption is the volume of gas at N.T.P. which is taken up by 1 c.c. of a liquid at the same pressure.

* *Vide* p. 13.

The coefficient of solubility is the ratio of the amount of gas in unit volume above, and in, the liquid.

Increase of temperature diminishes the coefficient of solubility. At the boiling-point it is equal to zero. In a mixture of two or more gases in contact with water (or any liquid) each gas will be dissolved to the same extent as if it were the only gas present.

Solutions.—A normal solution contains the hydrogen-equivalent of the substance in grammes dissolved in 1 litre of water at 15.5° C. or 60° F.

The "hydrogen-equivalent" of a reagent is its weight in grammes, which is chemically equivalent to 1 gramme of hydrogen.

The normal solution of a monovalent body contains its molecular weight in grammes per litre.

E.g., the normal solution of $NaHO = 23 + 1 + 16 = 40$ grammes per litre; of $HCl = 1 + 35.5 = 36.5$ grammes per litre.

In a divalent reagent the normal solution has *half* the molecular weight of the substance per litre, and in a trivalent body one-third of the molecular weight, *e.g.*:

Normal solution of barium hydrate $= \frac{Ba_2(HO)}{2} = \frac{137 + 2 \times (1 + 16)}{2}$

$= 85.5$ grammes per litre (divalent).

Of hydrated oxalic acid $= \frac{C_2H_2O_4 + 2H_2O}{2} = \frac{126}{2} = 63$ grammes per litre.

Normal solution of sodium phosphate (trivalent)

$$= \frac{Na_2HPO_4 + 12H_2O}{3} = \frac{358}{3} = 119.3 \text{ grammes per litre.}$$

In normal solutions 1 c.c. of any acid of whatever "valency" corresponds to 1 c.c. of any alkali.

A solution of half, $\frac{1}{10}$, $\frac{1}{100}$, &c., the normal strength is a "semi-" $\left(\frac{N}{2}\right)$, "deci-" $\left(\frac{N}{10}\right)$ or "centi-normal" $\left(\frac{N}{100}\right)$ solution.

"Standard solutions" other than "normal" may be made of any required strength without reference to valency.

If a solution is not of standard or normal strength it is titrated with one of standard strength and the "factor for correction" calculated.

EXAMPLE.—20 c.c. "normal" alkaline solution required 18.6 c.c. of the acid solution instead of 20 c.c. The alkaline standard being of proper strength proves the acid solution to be weaker than normal, and the factor for correcting the latter is calculated thus:

$$18.6 : 1 :: 20 : x. \qquad x = \frac{20}{18.6} = 1.075 \text{ as "factor."}$$

$\therefore$ c.c. of acid solution $\times$ 1.075 = correction to normal.

By working with 100 c.c. (= 100,000 mgr.) the results can be expressed at once in parts per 100,000. This is the best method, and is almost universally adopted in scientific research. By multiplying the results by 0.7 they are stated as "grains per gallon."

By taking 70 c.c. (= 70,000 mgr.) the returns are in "grains per gallon," and are changed to "parts per 100,000" by multiplying by $\frac{10}{7}$ or by 1.43, a less convenient process than the above. The statement of results in grains per gallon is practically limited to Great Britain, and is more readily understood by the Public and by Sanitary Authorities. Working with 70 c.c. instead of 100 may shorten the time in making an analysis, and this may be a *desideratum*. In all cases the result should be expressed also in parts per 100,000.

CHAPTER II.

SPECIFIC GRAVITY.

The calculation is based on the principle of Archimedes, that every body immersed in water or any fluid is subjected to an upward pressure equal to the weight of the liquid displaced by the body. There is a loss of weight equal to that of the displaced liquid. Two forces influence the body:

(*a*) One equal to its weight acting at the centre of gravity and tending to depress it.

(*β*) The other at its centre of buoyancy tending to raise it.

I. To Determine the Specific Gravity of a Solid.

1. Heavier than and insoluble in Water. A.—(*a*) Weigh it *in air* in a chemical balance in the ordinary way. (*b*) Suspend it by a very fine fibre (the weight of which may be neglected or estimated) from the hook of the balance-arm without removing the scale-pan, or from the hook beneath the pan, the substance being immersed in pure distilled water at 4° C., or more usually at 15·5° C., the ordinary temperature of a laboratory. Air-bubbles on the surface are to be brushed off gently. Air in the interior of a porous substance is removed by the air-pump or by boiling during immersion.

Weigh the substance a second time. The difference between this and the first weight in air is the loss of weight in water.

$$\frac{\text{Weight in air}}{\text{Loss of weight in water at } 4^\circ \text{ C.}} = \text{sp. gr.}$$

(or weight of an equal volume of water).

E.g., Weight in air = 136 grammes.
,, water = 121 ,,

Loss of weight in water = 136 − 121 = 15 grammes.

$$\frac{136}{15} = 9.06 = \text{sp. gr., or "density relative to water."}$$

Similarly for grain-weights.

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B. By Nicholson's hydrometer (constant immersion). A weight of 100 grammes placed on the tray (Fig. 1) sinks the instrument to the zero mark when it is immersed in distilled water, *i.e.*, weight of instrument + 100 grammes = weight of water displaced. The body of which the sp. gr. is to be estimated must be insoluble in water, and its weight less than 100 grammes and heavier than that of an equal bulk of water, so that it will sink.

(1) Place the body on the tray and add weights till the instrument sinks to zero. *E.g.*, 55 grammes must be added ∴ weight of body in air = 100 − 55 = 45 grammes.

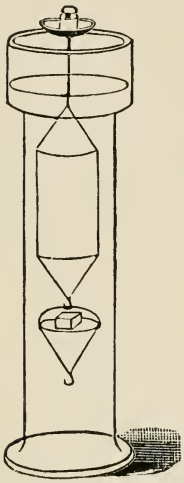

Fig. 1.—Nicholson's Hydrometer.

(2) Place the body in the "basket," under water, and add *additional* weights to those already in the tray until the instrument sinks again to the zero mark. *E.g.*, 34 grammes are added. This is equivalent to the weight of water displaced by the solid.

$$\therefore \text{ Sp. gr. of solid} = \frac{45}{34} = 1.3.$$

It can also be used for estimating the sp. gr. of a liquid denser than water: Let the instrument be placed in the liquid to be tested; add weights on the tray till the zero level is reached, *e.g.*, 65 grammes.

Let the weight of the instrument itself = 120 grammes.

$$\therefore \text{ Sp. gr. of liquid} = \frac{120+65}{120+100} = \frac{185}{220} = 0.84.$$

2. The Body is lighter than and insoluble in Water.—A "sinker" is used to keep the body under water. The weight of the sinker in air need not be known, but its weight in water must be ascertained and also that of any wire, &c., connecting it with the solid when under water.

Let S_a = weight of the solid in air.
s_w = ,, ,, ,, sinker in water.
Ss_w = ,, ,, ,, solid and sinker together in water.

The combined weights of both in water will be less than that of the sinker in water by itself, owing to the force of buoyancy tending to lift the body and sinker. This force is equal to s_w *minus* Ss_w.

∴ the weight of the liquid displaced, or the loss of weight in water = $(S_a + s_w) - Ss_w$.

$$\text{Sp. gr.} = \frac{S_a}{(S_a + s_w) - Ss_w}.$$

EXAMPLE.—Weight of the body in air = 48 grains.
" " sinker in water = 123 grains.
" in water of body and sinker = 94 grains.

$$\therefore \text{Sp. gr.} = \frac{48}{(48 + 123) - 94} = 0.623 \text{ (water = 1)}.$$

3. THE SOLID IS HEAVIER THAN WATER AND SOLUBLE IN IT.—The body is weighed in air and then in a fluid which will not dissolve it, and the *specific gravity of which is known.*

Let W_a = weight of solid in air (*e.g.* = 7.42 grammes).
W_l = " " liquid (= 4.34 grammes).
γ = sp. gr. of this liquid relative to water (= 0.76).

$$\therefore \text{Sp. gr. of solid relative to the liquid} = \frac{W_a}{W_a - W_l}$$

To express this relative to water: $\frac{\text{Sp. gr. of the liquid}}{\text{Sp. gr. of water}} = \frac{\gamma}{1} = \gamma$

$$\therefore \text{Sp. gr. of the solid relative to water} = \frac{W_a}{W_a - W_l} \times \gamma$$

$$= \frac{7.42}{7.42 - 4.34} \times 0.76 = 1.83$$

4. THE SUBSTANCE IS HEAVIER THAN AND INSOLUBLE IN WATER.—By the specific gravity bottle. A specific gravity bottle usually has engraved on it the weight of distilled water it can contain at standard temperature (15.5° C. or 60° F.) when filled up to a certain mark and properly stoppered.

An attached thermometer indicates the temperature of the contents.

The weight of the powdered substance being known, it is poured in.

Add distilled water to the powder already in the bottle, boil, and fill up to the mark with freshly boiled distilled water.

Weigh again at standard temperature.

Let W = weight of distilled water at standard temperature (*e.g.* = 50 grammes).
Let P = weight of dry powder (= 14 grammes).
P_w = " " powder + water (= 56.8 grammes).

$$\therefore \text{Sp. gr. of powder} = \frac{14}{(14 + 50) - 56.8} = 1.94.$$

5. The "specific gravity tube"—Sprengel's (Fig. 2) or Perkin's. One of the capillary tubes forming an "arm" has a mark etched on it indicating the point to which the liquid reaches. The other arm ends in a fine aperture through which the fluid to be tested is drawn by suction. Small glass caps are used to close the tubes and prevent evaporation. By means of a fine platinum wire of known weight the specific-gravity tube is suspended from the arm of the balance without removing the weighing-pan.

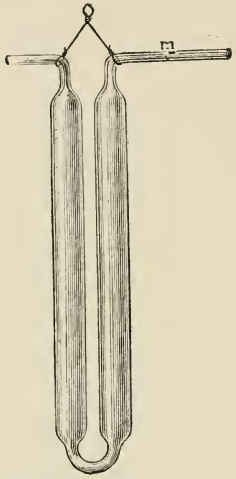

Fig. 2.—Sprengel's Specific Gravity Tube.

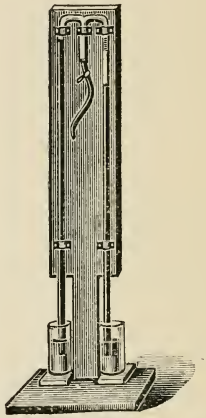

Fig. 3.—Hare's Apparatus.

Let the weight of the empty U-tube (clean and dry) = 10.398 grammes. Fill it with distilled water a little beyond the mark and warm the contents in a beaker of water at 15.5° C. Draw off the superfluous water with blotting-paper till the water is level with the mark. Dry, and weigh the tube and the contained water. Let this = 15.486 grammes.

Empty the tube of water, dry it in the air-bath, cool, and then fill it as before with the fluid to be tested. Weigh as before. Let this weight = 14.563 grammes.

$$\text{Sp. gravity of fluid} = \frac{14.563 - 10.398}{15.486 - 10.398} = \frac{4.165}{5.088} = 0.818.$$

This method is preferable to the sp. gr. bottle for temperatures above that of the atmosphere, and for liquids less dense than water —*e.g.*, alcohol.

6. Hare's apparatus; air is drawn out by the central tubing and the liquids rise in each tube.

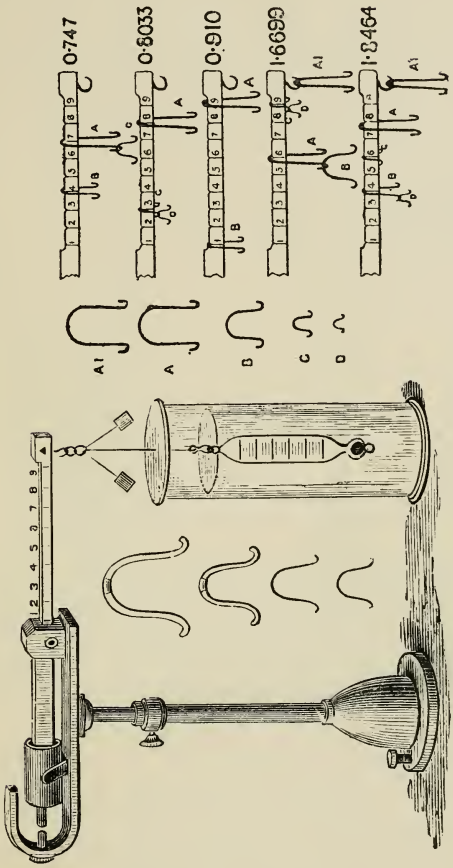

FIG. 4.—Westphal Balance.

Let H_l = height of the column of liquid.
H_w = ,, ,, ,, ,, water.

$$\therefore \text{Sp. gr.} = \frac{H_l}{H_w}.$$

As the heights of two columns of liquid in equilibrium are inversely as their specific gravities, the heavier liquid has the

shorter column and the greater sp. gr., the scales being marked in opposite directions to indicate this.

7. The specific gravity balance of Westphal (Fig. 4) or Sartorius (Fig. 5).

The plummet is immersed in the liquid at a known temperature (15.5° C. or 60° F.), and the riders are applied on the graduated arm till a perfect balance is obtained. The scale can be adjusted to the fourth decimal, and gives the sp. gr. relative to water as 1.

8. By hydrometers of variable immersion.

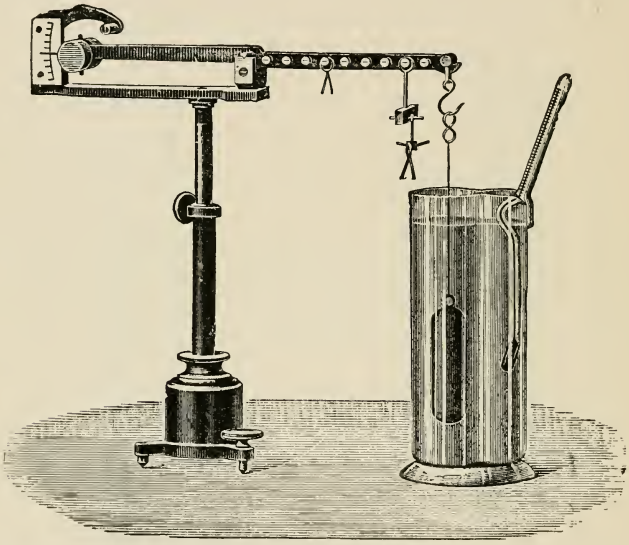

FIG. 5.—Sartorius' Balance.

Twaddell's (Fig. 6) is usually used in Britain for liquids denser than water. The divisions are at distances corresponding to equal differences of density and are not of the same length. The temperature of the liquid is to be 15.5° C. or 60° F.

The number of degrees read off multiplied by 5 and added to 1000 gives the sp. gr. relative to water as 1000. Thus "23.5" being the indicated reading:

$$\text{Sp. gr. of liquid} = (23.5 \times 5) + 1000$$
$$= 117.5 + 1000 = 1117.5.$$

If water is taken as 1, this becomes 1.1175.

Baumé's Hygrometers.—(*a*) For liquids denser than water ("salimeter"). The zero is at the top of the scale and is the point to which the instrument sinks in distilled water at 15.5° C. or 60° F. = 1.000 sp. gr. 10° = 1.075, 20° = 1.161, 30° = 1.263, 40° = 1.385, 50° = 1.532, 60° = 1.714, 70° = 1.946 sp. gr.

(*β*) For liquids less dense than water ("alcoholimeter"). The zero is at the bottom of the scale, and indicates a mixture of 10 parts by weight of salt and 90 parts by weight of water.

10° is the level in distilled water at 15.5° C. (60° F.) = 1.000 sp. gr. 20° = 0.928, 26° = 0.892, 30° = 0.871, 36° = 0.837, 40° = 0.817, 50° = 0.761, 60° = 0.706 sp. gr.

Fig. 6.—Twaddell's Hydrometer.

II. To Find the Specific Gravity of a Liquid relative to Water.

(1) By using a solid of known weight insoluble in either of the fluids.

A metal ball or plummet is taken and weighed:

(*a*) In air (*e.g.* = 118.7 grains).
(*b*) In distilled water (= 75.3 grains). } at 60° F.
(*c*) In the liquid itself (= 62.4 grains).

118.7 − 62.4 = weight of liquid displaced by the ball.

118.7 − 75.3 = „ „ water „ „ ball.

$$\therefore \text{ Sp. gr. of the liquid} = \frac{118.7 - 62.4}{118.7 - 75.3} = 1.3.$$

(2) By the specific gravity bottle for liquids.

Let weight of empty bottle = 25.623 grains.
„ „ bottle + distilled water at 15.5° C. = 78.658 grains.
„ „ „ + liquid at 15.5° C. = 67.581 grains.

67.581 − 25.623 = 41.958 = weight of liquid.
78.658 − 25.623 = 53.035 = „ „ water.

$$\therefore \text{ Sp. gr. of liquid} = \frac{41.958}{53.035} = 0.791.$$

To Calculate the Weight of Aqueous Vapour or "Moisture" present in a Mixture of Air and Vapour at a given Temperature and Pressure.

1. Find the weight of the same volume of dry air corrected for N.T.P. under similar conditions of temperature and pressure.

2. Multiply the result by the specific gravity or relative density of the vapour, air being taken as unity. This is as 0.623 to 1. If the pressure is not stated it must be ascertained from a Table of Pressures (or "Tensions") of Aqueous Vapour (Regnault's). Opposite each degree and tenth of a degree C. is given the maximum tension in mm. of mercury. This is read off for the given temperature.

EXAMPLE.—Calculate the weight of 1 litre of aqueous vapour at 15.5° C.

(1) $V_1 = 1$ litre. V_2 is to be calculated. P_1 is found from the Table of Vapour Tensions (p. 27). Opposite "15.5 C." is "13.1," *i.e.* = maximum pressure of aqueous vapour at that temperature.

Let W = weight of 1 litre of dry air at 15.5° corrected for N.T.P. 1 litre of dry air at N.T.P. weighs 1.293 grammes.

$$\therefore\ W = \frac{13.1 \times 273 \times 1}{760 \times (273 + 15.5)} \times 1.293 = 0.016 \times 1.293 = 0.0207 \text{ gramme.}$$

(2) $0.0207 \times 0.623 = 0.0128961$ gramme = weight of 1 litre of aqueous vapour at 15.5° C. and 13.1 mm. pressure.

If the Table of Vapour Tensions expresses Temperature and Pressure only in C.° and mm. and the equivalents are required in F.° and inches, the conversion to the latter is easily made. For temperature, as already indicated (pp. 2, 3); and for pressure as follows:

1 millimetre = 0.03937 inch

∴ "Tension in millimetres of mercury" × 0.03937 = Tension in inches of mercury (*i.e.*, "pressure").

EXAMPLE.—15.5° C. = 13.1 mm. (Regnault). To convert to F.° and inches:

$$\frac{15.5}{5} = \frac{F - 32}{9}. \quad F = 59.9 \text{ or } 60^\circ \text{ (nearly)}.$$

and $13.1 \times 0.03937 = 0.515747$ inch.
$= 0.516$ inch (nearly).

∴ "15.5° C. and 13.1 mm." correspond to 60° F. and 0.516 inch.

EXAMPLE.—Find the weight of 2 cubic feet of aqueous vapour at 60.8° F.

Pressure not being given, it is found from an Aqueous Vapour-Tension Table:

60.8° F. = 0.5315 inch (= maximum pressure).

(1) Find the weight of an equal volume of dry air, denoted by "W." 1 cb. ft. of dry air at N.T.P. weighs 567 grains.

$$\therefore W = \frac{0.5315 \times (459 + 32) \times 2}{30 \times (459 + 60.8)} \times 567 \text{ grains.}$$

$$= \frac{0.5315 \times 491 \times 2}{30 \times 519.8} \times 567 = 18.9 \text{ grains.}$$

(2) 18.9 × relative density (or weight) of aqueous vapour = 18.9 × 0.623 = 11.77 grains, the required weight of aqueous vapour.

Pressure, Tension, or Elastic Force of Aqueous Vapour from 0° to 30° C.

In mm. of mercury.

C°. Mm.	C°. Mm.	C°. Mm.	C°. Mm.	C°. Mm.
0.0...4.6	6.5 .. 7.2	13.0...11.2	19.5...16.9	26.0...25.0
0.5...4.8	7.0 .. 7.5	13.5...11.5	20.0...17.4	26.5...25.7
1.0...4.9	7.5 .. 7.8	14.0...11.9	20.5...17.9	27.0...26.5
1.5...5.1	8.0... 8.0	14.5...12 3	21.0...18.5	27.5...27.3
2.0...5.3	8.5... 8.3	15.0...12.7	21.5...19.1	28.0...28.1
2.5...5.5	9.0... 8.6	15.5...13.1	22.0...19.7	28.5...28.9
3.0...5.7	9.5... 8.9	16.0...13.5	22.5...20.3	29 0 ..29.8
3.5...5.9	10.0... 9.2	16.5...14.0	23.0 ..20.9	29 5...30.7
4.0.. 6.1	10.5... 9.5	17.0...14.4	23.5...21.5	30.0...31.5
4.5...6.3	11.0... 9.8	17.5...14.9	24.0...22.2	
5.0...6.5	11.5...10.1	18.0...15.4	24.5...22.9	
5.5...6.8	12.0...10.5	18.5...15.8	25.0 23.5	
6.0...7.0	12.5...10.8	19.0...16.3	25.5...24.3	

Pressure, Tension, or Elastic Force of Aqueous Vapour from 32° to 90° F.

In inches of mercury.

F°.	Inches.	F°.	Inches.	F°.	Inches.	F°.	Inches.	F°.	Inches.
32	0.181	44	0.288	56	0.449	68	0.684	80	1.023
33	0.188	45	0.299	57	0.465	69	0.708	81	1.057
34	0.196	46	0.311	58	0.482	70	0 733	82	1.092
35	0.204	47	0.323	59	0.500	71	0.759	83	1.128
36	0.212	48	0.335	60	0.518	72	0.785	84	1.165
37	0.220	49	0.348	61	0.537	73	0.812	85	1.203
38	0.229	50	0.361	62	0.556	74	0.840	86	1.242
39	0.238	51	0.374	63	0.576	75	0.868	87	1.282
40	0.247	52	0.388	64	0.596	76	0.897	88	1.323
41	0.257	53	0.403	65	0.617	77	0.927	89	1.366
42	0.267	54	0.418	66	0.639	78	0.958	90	1.410
43	0.277	55	0.433	67	0.661	79	0.990		

Tensions at intermediate temperatures are approximately calculated by taking the Arithmetical Mean of the tensions given in the table, at temperatures immediately above and below the given temperature.

Example.—Find the approximate tension of aqueous vapour at 56.5° F. and 79.5° F.

Vide Table: 56° F. = 0.449 inch.
57° F. = 0.465 „
2)0.914
0.457 inch = approximate tension at 56.5° F.

79° F. = 0.990 inch.
80° F. = 1.023 „
2)2.013 inch.
1.006 inch = approximate tension at 79.5° F.

To Calculate the Weight of a given Volume of Air saturated with Moisture at a given Temperature and Pressure.* —Consider the total volume of saturated air to consist of a volume of dry air *plus* a volume of aqueous vapour.

1. Calculate the weight of an equal volume of each at the same temperature and at their respective pressures.

* *Vide* pp. 12, 14.

2. Add these results together: their sum is the weight of saturated air.

To work out the pressure of aqueous vapour, Tables are necessary, as already indicated.

Let P = total pressure of the combined volumes of "dry" air and aqueous vapour.

Let p = pressure of aqueous vapour only.

$\therefore$ P $- p$ = pressure of "dry" air.

EXAMPLE.—Find the weight of 1 litre of air saturated with moisture at 15° C. and 730 mm. pressure.

P = 730 mm. = pressure of combined volumes.

p at 15° C. = 12.7 mm. (*vide* Table).

P $- p$ = 730 − 12.7 = 717.3 = pressure of "dry" air.

1. (*a*) Volume of dry air at 15° C. and 717.3 mm. $= \frac{717.3 \times 273 \times 1}{760 \times (273 + 15)}$ = 0.89 litre. Its weight = 0.89 × 1.293 = 1.15 gramme.

1. (*b*) Volume of aqueous vapour at 15° C. and 12.7 mm. $= \frac{12.7 \times 273 \times 1}{760 \times (273 + 15)} = 0.158$ litre.

Its weight = 0.158 × 1.293 = 0.204 gramme,

And 0.204 × 0.623 (relative density of aqueous vapour) = 0.127 gramme.

$\therefore$ Weight of saturated air = 1.15 + 0.127
= 1.277 gramme.

EXAMPLE.—Find the weight of 1 cubic foot of saturated air at 60° F. and 30 inch pressure.

P = pressure of combined volumes = 30 inches
p = ,, ,, aqueous vapour at 60° F. = 0.518 inch
P $- p$ = ,, ,, "dry" air = 30 − 0.518 = 29.482 inches

(1) (*a*) Volume of 1 cubic foot of dry air at 60° F. and 29.482 inches.

$= \frac{29.482 \times (459 + 32) \times 1}{30 \times (459 + 60)} = \frac{29.482 \times 491 \times 1}{30 \times 519} = 0.929$ cubic inch.

Its weight = 0.929 × 567 = 526.743 grains.

(*b*) Volume of 1 cubic foot of aqueous vapour at 60° and 0.518 inch.

$= \frac{0.518 \times 491 \times 1}{30 \times 519} = 0.016$ cubic inch.

Its weight = 0.016 × 567 = 9 072 grains.

9.072 × relative density of aqueous vapour = 9.072 × 0.623 = 5.652 grains.

∴ Weight of saturated air at 60° F. and 30 inches

$$= 526.743 + 5.652 = 532.395 \text{ grains.}$$

The weight of 1 cubic foot of dry air at 60° F. and 30 inches is

$$\frac{30 \times 491 \times 1}{30 \times 519} \times 567 = 536.38 \text{ grains.}$$

So that a volume of moist or saturated air is *lighter* than an equal volume of *dry* air under the same temperature and pressure.

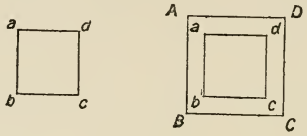

FIG. 7.

The diminution in density and weight is due to expansion of total volume.

Let *a b c d* (Fig. 7) represent 1 cubic foot of dry air and A B C D the increased volume of this air *plus* moisture, 1 cubic foot *a b c d* of this augmented volume will weigh less than the same volume of dry air because of expansion and rarefaction, but the weight of the volume A B C D will, of course, be greater.

"Dry air" denotes air containing no aqueous vapour—*i.e.*, its "humidity is zero." Humidity of the air is the weight of aqueous vapour present in a given volume of air, expressed as a percentage of the weight of vapour at saturation which would occupy the same volume at the actual temperature. (Everett.)

A volume of air at any temperature can contain a definite quantity of water vapour. When the contained water vapour is the greatest amount possible at that temperature, the air is "saturated." It is then at maximum humidity. This is the "dew-point," which is therefore the temperature of saturation (*vide* p. 32).

Air holding less than its maximum amount of aqueous vapour will be saturated by that same quantity of moisture when its temperature falls to dew-point. If in excess, moisture is deposited on solid surfaces, forming dew.

"Absolute humidity" or "absolute moisture" is the weight of water vapour (expressed as grammes or grains) actually present in a known volume of air at a certain temperature.

It is estimated by ascertaining from Tables the maximum pres-

sure or tension of water-vapour at the temperature of the dew-point.

e.g. Dew-point = 49° F. Tension = 0.348 in. = Absolute humidity.

"Relative humidity" is expressed as :

(1) Weight of water actually present in a known volume of air / Weight of water which would saturate the same volume of air

Or :

(2) Tension of aqueous vapour at the temperature of the dew-point / Tension of aqueous vapour at the temperature of the dry bulb

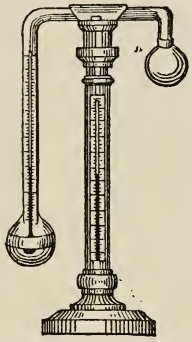

Fig. 8.—Daniell's Hygrometer.

By the first method the weight of water is calculated as already indicated (pp. 26, 29).

In the second formula the vapour tensions are obtained from a Table :

Example.—Dew-point temperature = 52° F. = 0.388 inch.
Dry-bulb ,, = 63° F. = 0.576 ,,
(*Vide* Tables.)

$$\therefore \text{ Relative humidity} = \frac{0.388}{0.576} = 0.674 \text{ (nearly).}$$

Here saturated air is taken as 1 ; in 100 parts the relative humidity is 67.4 per cent. of saturation, or 0.674 × 100.

On the Continent "maximum moisture" denotes the maximum quantity of aqueous vapour which air can take up at a certain temperature. A volume of air at any known temperature can contain a definite quantity of water vapour, and Tables of maximum moisture at various temperatures are constructed.

The difference in pressure between maximum (saturation) and absolute moistures is known as the "deficiency of saturation."

Example.—Relative moisture = 70 per cent. Temperature = 17° C.

Find the absolute moisture.

At 17° C. maximum moisture = 14.4 mm. (per Table).

$\therefore$ 100 : 14.4 : : 70 : x. x = 10.08 absolute moisture.

14.4 − 10.08 = 4.32 = deficiency of saturation (Lehmann).

In this country complete saturation is denoted as 100 parts by

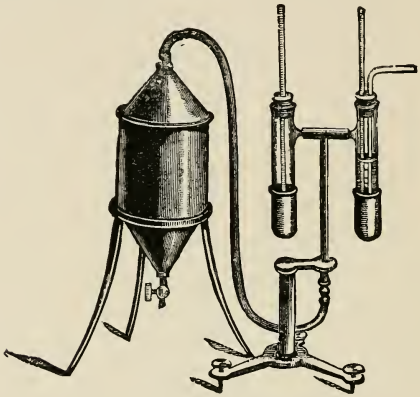

Fig. 9.—Regnault's Hygrometer.

weight of aqueous vapour and relative humidity is expressed as a percentage of saturation.

A relative humidity of 75 per cent. means, therefore, 75 per cent. of saturation.

The drying power of the air is 100 − relative humidity, so that 100 − 75 = 25 per cent., which is the drying-power of the air with a relative humidity of 75.

The dew-point is ascertained (1) directly by hygrometers or "instruments of condensation"—Daniell's (Fig. 8), Regnault's (Fig. 9), or Dines' (Figs. 9*a*, 9*b*). (2) By hygrometers of absorption: (*a*) De Saussure's, consisting of a weighted human hair free from grease, which elongates as humidity increases and contracts as it diminishes and moves an index; (*b*) by the chemical hygrometer, consisting of U-tubes (containing a dry hygroscopic substance) which are weighed before and after the aspiration through them of a known volume of moist air. (3) Indirectly by the dry- and wet-bulb thermometer or psychrometer (hygrometer of evaporation) with Glaisher's or Apjohn's formula.

I. Directly.

In all cases take the reading twice: (*a*) the moment the film of moisture appears; (*b*) when it disappears. The mean of these observations gives the correct dew-point temperature. If only one reading is taken the first would be a little below, and the second a little above the true dew-point.

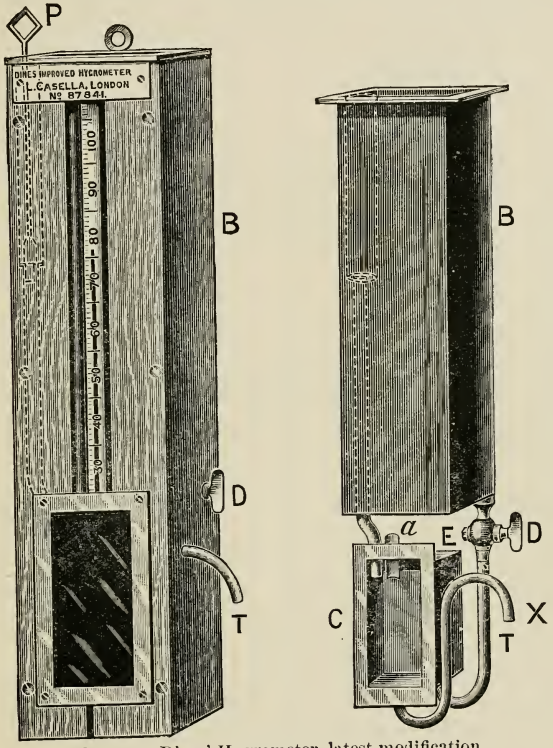

FIG. 9*a*.—Dines' Hygrometer, latest modification.

B reservoir for ice-cold water turned on by tap D.
P plug in separate tube for running ether instead of water into chamber C containing thermometer-bulb and covered by black glass slab for observing moisture.

EXAMPLE.—Temperature when film forms 49.6° F.
" " " disappears 49.8° F.
2)99.4°
Dew-point = 49.7° F.

The mean of a series of observations is more accurate.

II. Indirectly by the dry- and wet-bulb hygrometer or psychrometer.

(*a*) Glaisher's Formula.—This is an empirical one, founded on observations extending over several years in various latitudes.

To use this method a Table of Glaisher's Factors (for each reading of the *dry*-bulb thermometer) is indispensable.

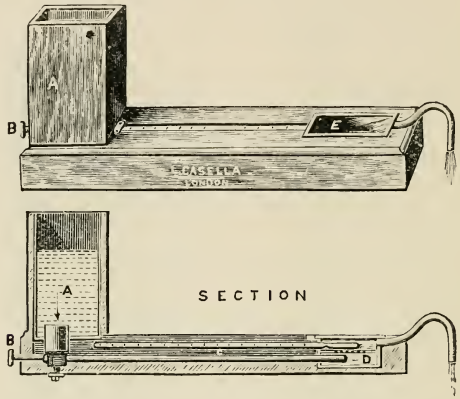

FIG. 9*b*.—Dines' Hygrometer, old pattern.

METHOD.—(1) Take the reading of the dry- and wet-bulb thermometers at the same time.

(2) Subtract the latter reading from the former.

(3) Multiply the difference by the "factor" (*vide* Table) corresponding to the dry-bulb temperature.

(4) Deduct the product from the dry-bulb reading.

Let T_d = Temperature of the dry-bulb.
T_w = ,, ,, ,, wet-bulb.
F = Glaisher's factor opposite the dry-bulb temperature.

$$\therefore \text{Dew-point} = T_d - \{(T_d - T_w) \times F.\}$$

EXAMPLE.—$T_d = 62^\circ$ F.
$T_w = 51^\circ$ F.
F (at 62° F.) = 1.86.

$$\therefore \text{Dew-point} = 62 - \{(62 - 51) \times 1.86\}$$
$$= 62 - \{11 \times 1.86\}$$
$$= 62 - 20.46$$
$$= 41.54^\circ \text{ F.}$$

TABLE OF GLAISHER'S FACTORS.

Hygrometrical Tables, adapted to the use of Dry- and Wet-Bulb Thermometers, by JAMES GLAISHER, F.R.S., &c., 1885.

Reading of Dry-Bulb Thermometer.	Factor.	Reading of Dry-Bulb Thermometer.	Factor.	Reading of Dry-Bulb Thermometer.	Factor.	Reading of Dry-Bulb Thermometer.	Factor.
Fahr.		Fahr.		Fahr.		Fahr.	
10	8.78	33	3.01	56	1.94	79	1.69
11	8.78	34	2.77	57	1.92	80	1.68
12	8.78	35	2.60	58	1.90	81	1.68
13	8 77	36	2.50	59	1.89	82	1.67
14	8.76	37	2.42	60	1.88	83	1.67
15	8.75	38	2.36	61	1.87	84	1.66
16	8.70	39	2.32	62	1.86	85	1.65
17	8.62	40	2.29	63	1.85	86	1.65
18	8.50	41	2.26	64	1.83	87	1.64
19	8.34	42	2.23	65	1.82	88	1.64
20	8.14	43	2.20	66	1.81	89	1.63
21	7.88	44	2.18	67	1.80	90	1.63
22	7.60	45	2.16	68	1.79	91	1.62
23	7.28	46	2.14	69	1.78	92	1.62
24	6.92	47	2.12	70	1.77	93	1.61
25	6.53	48	2.10	71	1.76	94	1.60
26	6.08	49	2.08	72	1.75	95	1.60
27	5.61	50	2.06	73	1.74	96	1.59
28	5.12	51	2.04	74	1.73	97	1.59
29	4.63	52	2.02	75	1.72	98	1.58
30	4.15	53	2.00	76	1.71	99	1.58
31	3.60	54	1.98	77	1.70	100	1.57
32	3.32	55	1.96	78	1.69		

(*b*) Apjohn's Formula.—By this method the *vapour tension*, or pressure, at the temperature of the dew-point is first obtained, and from it the dew-point is ascertained by reference to a Table of Vapour Tensions. The use of this Table is therefore indispensable for working Apjohn's formula.

METHOD.—I. Vapour tension at the dew-point.

(1) Observe the readings of the dry- and wet-bulb thermometers at the same time.

(2) From a table of vapour tensions obtain the pressure in inches of mercury at the temperature of the *wet*-bulb.

(3) Note the height of the barometer in inches. If nearly at sea-level pressure (30 inches) this may be neglected.

Let T_d = Temperature of the dry-bulb (*i.e.* of the air).
T_w = „ „ wet-bulb.
V.p.$_w$ = vapour pressure at the temperature of the wet-bulb.
H = height of the barometer.

Vapour pressure at the dew-point

$$= \text{V.p.}_w - \left(\frac{T_d - T_w}{87} \times \frac{H}{30}\right) \text{ for temperatures } \textit{above } 32^\circ \text{ F.}$$

$$= \text{V.p.}_w - \left(\frac{T_d - T_w}{96} \times \frac{H}{30}\right) \quad \text{„} \quad \textit{below } 32^\circ \text{ F.}$$

The height at sea-level is practically 30″, so that the fraction $\frac{H}{30} = \frac{30}{30} = 1$, and may therefore be neglected, and the formula then becomes:

Vapour pressure at the dew-point $= \text{V.p.}_w - \frac{T_d - T_w}{87 \text{ (or } 96)}$ *i.e.*, as the temperature of the air (dry-bulb) is above or below 32° F.

II. Having obtained the vapour pressure at the dew-point expressed in inches, ascertain from the Table the temperature corresponding to this tension. This gives the "dew-point" itself.

Example.—Taking the same temperatures as in the last example of Glaisher's Formula:

I. $T_d = 62^\circ$ F., $T_w = 51^\circ$ F.
Vapour tension at $T_w = 0.374$ inch. (*Vide* Pressure Tables, p. 28.)
B = 28.9 inches.

$$\therefore \text{ Vapour tension at dew-point} = 0.374 - \left(\frac{62 - 51}{87} \times \frac{28.9}{30}\right)$$
$$= 0.374 - \left(\frac{11}{87} \times 0.963\right)$$
$$= 0.374 - 0.122$$
$$= 0.252 \text{ inch.}$$

II. In the Table of Aqueous Vapour Pressures 0.252 is not given,

but it lies between 0.247 and 0.257, which respectively correspond to 40° F. and 41° F. 0.252 is found to be the mean of these pressures: $\frac{0.247+0.257}{2}=0.252$, and the corresponding temperature may be taken as approximately the mean of 40° and 41° F., *i.e.*,

$$\frac{40+41}{2}=40.5^\circ \text{ F.}$$

$\therefore$ Dew-point = 40.5° F.

The result obtained by Glaisher's Formula is 41.54° F., so that the discrepancy is the comparatively slight one of 1.04° F.

Weight of Air.—Method.—A glass globe fitted with a stop-cock and of known capacity (preferably 12 to 13 litres) is exhausted of air and weighed in a balance ("baroscope," Fig. 10). After equilibrium is established dry air is admitted by opening the stop-cock, and the weight of the globe is taken again.

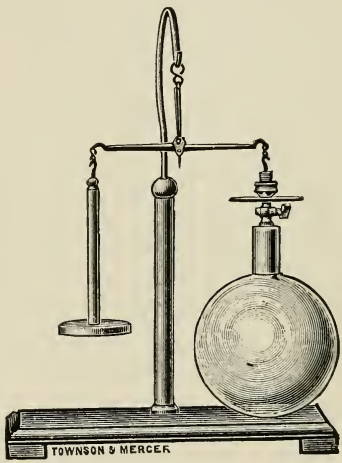

Fig. 10.—Baroscope.

Example.—Capacity of globe = 13 litres.

Difference in weight between globe when full of air and when exhausted of air = 16.809 grammes.

Weight of air $=\frac{16.809}{13}=$ 1.293 grammes per litre, which is the weight of dry air at N.T.P.

If the density of 1 litre of water is taken as 1000 (at 4° C.) the ratio of an equal volume of dry air to it is $\frac{1.293}{1000}=\frac{1}{773}$ (= 0.00129) —*i.e.*, air is 773 times lighter than water; *vice versâ*, water is 773 times heavier than air.

In a mercurial barometer the usual height of the column is 30 inches (2.5 feet); mercury being 13.6 times denser than water, in a water barometer the equivalent height is $2.5\times13.6=34$ feet.

Glycerine is 1.26 times denser than water (= 1), the height of the column of the glycerine barometer is therefore less, varying inversely as the density.

To calculate it from the above data: 1.26 : 1 : : 34 : $x=27$ feet.

Again: mercury is nearly ten times denser than glycerine $\left(\frac{13.6}{1.26}\right)$

$\therefore$ 1.26 : 13.6 : : 30 : $x = 27$ feet (as before).

$\therefore$ Mercurial column 30 inches = water column 34 feet = glycerine column 27 feet.

Barometric Corrections.

1. **Correction for Capacity.**—This is not necessary in the Fortin, Kew, and Siphon barometers. Howson's and McNeild's long-range barometers are self-adjusting, the bore of the tube is not less than one inch, and they are unaffected by differences of level in the cistern and need no adjustment for the neutral point. In the Fortin barometer the mercury in the cistern is raised or lowered to the correct level ("fiducial point") by means of a screw at the base of the instrument.

The Kew barometer has corrections all along the scale, which is divided into shortened, and not true, linear inches. (The divisions are less than true inches in the ratio of $\frac{C}{C+T}$. (*vide infra*).

The siphon barometer adjusts itself as the rise in one limb is compensated by a fall in the other, and *vice versâ*, and the true reading is the difference of level in its two scales.

Barometers not having the above adjustments have a "neutral point" marked on the scale of the instrument. At this point the mercurial column gives the correct reading, and the mercury in the cistern is at the proper level.

Let T = internal sectional area in square inches of the barometer tube.

Let C = area of the cistern after deducting that occupied by the tube and its contents.

Let D = distance in inches of the summit of the mercurial column from the neutral point—above or below it.

$$\text{Correction} = D \times \frac{T}{C}.$$

This is to be added to the observed reading if the mercurial column is above the neutral point, and to be subtracted if below that point. The "correction" is calculated and supplied with each instrument by the makers.

EXAMPLE.—$\frac{T}{C} = \frac{1}{50}$ ("correction").

Observed reading = 30.560 inches, summit of column being $\frac{3}{4}$ of an inch *above* the neutral point.

$\therefore$ Correction $= \frac{3}{4} \times \frac{1}{50} = 0.015$ inch.

As the mercurial column is above the neutral point, this is to be added to the observed height;

$\therefore$ 30.560 + 0.015 = 30.575 inches as the correct height.

2. **Correction for Capillarity.**—Unless the internal diameter of the barometer tube exceeds 0.6 inch, the mercurial column is slightly, and appreciably, depressed by capillary action due to surface tension between the surfaces of mercury and glass. If the mercury has been boiled in the tube the depression is reduced to half what it would be if unboiled. The correction is always to be *added* to the observed reading, and is calculated from the height of the meniscus and from the internal diameter of the tube. Tables of correction are supplied with each instrument. The Kew Certificate gives the capacity and capillarity corrections and index error in one figure for all readings.

Table of Corrections for Capillarity (only), to be added to all Readings.

N.B.—To be *halved* for Boiled Tubes.

Diameter of Tube.	Depression in Unboiled Tube.
Inch.	Inch.
0.60	0.004
0.55	0.005
0.50	0.007
0.45	0.010
0.40	0.015
0.35	0.021
0.30	0.029
0.25	0.041
0.20	0.058
0.15	0.086
0.10	0.140

3. **Correction for Index Errors.**—These include (1) errors in position of the zero-point, and (2) errors of graduation along the scale, and are special for each instrument. "An error of zero makes all readings too high or too low by the same amount." The Kew corrections include index error, capacity and capillarity

errors at every half-inch of the scale. No instrument is passed as a "Standard" if the errors exceed 0.01 inch.

4. **Correction for Temperature,** or "Reduction to 32° F."—Variations in temperature cause expansion or contraction of both the mercury and the metallic scale of graduations.

Each of these must be corrected in a Standard barometer.

(1) Correction for the mercury only.

(*a*) In the Fahrenheit scale the coefficient of expansion of mercury is $\frac{1}{9990} = 0.0001$ per 1° F., *i.e.*, it expands $\frac{1}{9990}$ of its length at 32° F. for each 1° F. above that temperature.

It also contracts to the same extent per each degree below 32° F.

Reducing to the temperature of 32° F.:

Corrected height of barometer at

$$32° \text{ F.} = \frac{\text{Observed height of barometer}}{1 + \{0.0001 \times (\text{F.}° - 32)\}}.$$

"F." = temperature of the thermometer *attached to the barometer*, which indicates the *temperature of the column of mercury*.

EXAMPLE.—Observed height of barometer = 29.5 inches.
,, temperature of attached thermometer = 58.6° F.

$$\text{Corrected height at } 32° \text{ F.} = \frac{29.5}{1 + \{0.0001 \times (58.6 - 32)\}}$$

$$= \frac{29.5}{1 + \{0.0001 \times 26.6\}} = \frac{29.5}{1.00266} = 29.42 \text{ inches.}$$

(*b*) In the Centigrade scale the coefficient of expansion of mercury per 1° C. is $\frac{1}{5550} = 0.00018$, and reducing to 0° C.:

Corrected height of barometer at 0° C.

$$= \frac{\text{Observed height of barometer}}{1 + \{0.00018 \times \text{C.}°\}}.$$

NOTE.—The observed height is expressed in millimetres. C° = reading in Centigrade degrees of *attached* thermometer.

EXAMPLE.—Observed height = 761.75 mm.
,, temperature = 8.6° C.

$$\text{Corrected height at } 0° \text{ C.} = \frac{761.75}{1 + \{0.00018 \times 8.6\}} = \frac{761.75}{1.001548}$$

= 760.72 mm.

(2) Corrections for both the mercury and the brass-scale.

(*a*) FAHRENHEIT.—The coefficient of expansion of brass per 1° F. at 62° F. = 0.00001. (N.B. $\frac{1}{10}$ less than the corresponding coefficient of expansion of mercury.)

Corrected height at 32° F. (*i.e.* True reading) } = Observed height of barometer *minus*:

{*Observed height of barometer* × (F.° − 32) × 0.000089.}

(F.° = temperature of attached thermometer.)

NOTE.—"0.000089" = coefficient of expansion of Hg, *minus* ditto of brass, *i.e.*, 0.0001 − 0.00001.

NOTE.—The correction must be subtracted from the "observed height," which term *occurs twice* in the formula as given above.

EXAMPLE.—Observed height of barometer = 31.5 inches.
Observed temperature of mercurial column indicated by attached thermometer = 58° F.

∴ *Corrected height at*

32° F. = 31.5 − {31.5 × (58 − 32) × 0.000089}
= 31.5 − {31.5 × 26 × 0.000089}
= 31.5 − 0.729
= *30.771 inches.*

(*b*) CENTIGRADE.—The coefficient of expansion of brass for each degree is 0.000018, and of mercury 0.00018.

Corrected height at
0° C. = Observed height − {Observed height × C.° × 0.00016}.
C = temperature of attached thermometer in Centigrade degrees.

EXAMPLE.—Observed height = 787.1396 mm.
Observed temperature = 14.5° C.

Corrected height at

0° C = 787.1396 − {787.1396 × 14.5 × 0.00016}
= 787.1396 − 13.1609...
= *773.978 mm.*

NOTE.—"0.00016" = coefficient of expansion of mercury, *minus* coefficient of expansion of brass, *i.e.* = 0.00018 − 0.000018.

Schumacher's formula for the correction for mercury and the brass-scale, reduced to 32° F., is as follows:

F = temperature of attached thermometer in degrees Fahrenheit.
0.0001 = coefficient of expansion of mercury at 32° F.
0.00001 = coefficient of expansion of brass-scale at standard temperature of *62° F.*

Corrected height at 32° F.

= Observed height, *minus* or *plus*:

$$\left\{\text{Observed height} \times \frac{0.0001 \times (\text{F.} - 32) - 0.00001\ (\text{F.} - 62)}{1 + 0.0001\ (\text{F.} - 32)}\right\}.$$

The "*Correction*" is to be *subtracted* (−) from the observed height at 29° F. and all higher temperatures, but is to be *added* (+) to it for all temperatures below 29° F. *See* Table of Corrections (Scott).

Corrections to be applied to Barometers with Brass Scales extending from Cistern to the top of the Mercurial Column to reduce the observation to 32° F.

Temperature.	Observed Height of Barometer in Inches.						
Degrees F.	28.0	28.5	29.0	29.5	30.0	30.5	31.0
27	+0.004			All through.			
28	+0.001			,,			
29	−0.001			,,			
30	−0.004			,,			
40	−0.029	0.029	0.030	0.030	0.031	0.031	0.032
50	−0.054	0.055	0.056	0.057	0.058	0.059	0.060
60	−0.079	0.080	0.082	0.083	0.085	0.086	0.087
70	−0.104	0.106	0.108	0.109	0.111	0.113	0.115
80	−0.129	0.131	0.133	0.136	0.138	0.140	0.143
90	−0.153	0.156	0.159	0.162	0.164	0.167	0.170
100	−0.178	0.181	0.184	0.188	0.191	0.194	0.197

5. **Corrections for Altitude, or "Reduction to Sea-Level."**—If the atmosphere were a homogeneous medium of uniform and constant density and incompressible, its height could be calculated from the pressure at sea-level as observed by the barometer, and from the densities or weights of air and mercury relative to water.

Weight of atmosphere at sea-level = mercurial column 30 inches high.

$$\left.\begin{array}{l}\text{Weight of air} = 0.00129\left(\frac{1}{773}\right) \quad . \quad . \quad . \\ \text{,,} \quad \text{,, mercury} = 13.6, \textit{i.e.}, 10543 \text{ times that of air}\end{array}\right\} \text{water} = 1.$$

$\therefore$ 0.00129 : 13.6 : : 30 : height of atmosphere ("homogeneous").

$\therefore$ height of atmosphere $= \frac{13.6 \times 30}{0.00129} = 316{,}000$ inches, 26,333 feet, or nearly 5 miles.

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In a homogeneous atmosphere the fall of the barometer would be regular, the pressure diminishing with the ascent, and depending on the weight of the vertical column of air between points at different levels. By the simple proportion:

30 inches : 1 inch :: 26333 feet : x feet.

The fall would be 1 inch for every 877.8 feet of ascent, or in round numbers about 880 feet. This does not hold good, because air is not a homogeneous medium, and is affected by pressure, temperature, movement (wind) and moisture. The average fall in the barometer is, therefore, determined by experiment, and is only an approximate estimate. In Great Britain the decrease is 1 inch for every 900 feet of ascent from sea-level—*i.e.*, 0.001 inch per foot, omitting variations of temperature, pressure, &c.

For the British Isles the standard sea-level adopted by the Ordnance Survey and Meteorological Offices is the mean sea-level at Liverpool—*i.e.*, half the average range of fluctuation between high- and low-water mark. From this "datum" altitudes of all localities are calculated, and are marked on the Ordnance Bench Marks and Survey maps.

All barometric observations must be reduced to sea-level, and corrected to standard temperature (32° F.) for comparison. The "correction" for places above sea-level is to be *added* to the observed local reading; and to be *subtracted* for localities below sea-level which are exceptional.

If n = altitude of place above sea-level in feet.
x = correction for altitude in inches.
900 : n :: 1 : x. $x = n \times 0.001$ inch.

Example.—Altitude = 4500 feet above sea-level.

Observed reading at this altitude = 27.3 inches (corrected to 32° F.).

"*Correction*" 1 : 4500 :: 0.001 : x. $x = 4.5$ inches.

Reduction to sea-level = 27.3 + 4.5 = 31.8 inches.

For correct records the temperature of the air must be taken by a dry-bulb thermometer, and *not* by the instrument attached to the barometer, and the pressures of the barometer should be taken, if possible, *simultaneously at the higher altitude and at the sea-level.*

Correction for Unequal Intensity of Gravity.—This is usually omitted. It is calculated as follows:

Let H = height of barometer in inches at 32° F.
G = acceleration due to gravity in feet (= 32 ft. per second).
13.6 = density of mercury relative to water at 32°.
Absolute pressure = H × G × 13.6.

To convert Barometric Readings in Inches into Millimetres.

1 metre at 0° C. = 39.37 inches or 3.3 feet.
1 inch at 0° C. = 25.4 mm.

Therefore, a reading of 31.4 inches = $31.4 \times 25.4 = 797.56$ mm.

A fall of 1 inch for every 900 feet of ascent corresponds to a fall of 25.4 mm. for 274 metres, which is approximately a fall of 1 mm. of mercury for every 10.8 (or 11) metres of altitude.

The "correction" is therefore as follows:

Let n = altitude of place above sea-level in metres.
x = correction for altitude in mm.

$$11 : n :: 1 : x.$$

Example.—Altitude above sea-level = 468 metres.
Observed reading at 20° C. reduced to 0° C. = 740 mm.

"*Correction*" $11 : 468 :: 1 : x$. $x = 42.5$.

Reduction to sea-level = $740 + 42.5 = 782.5$ mm.

Formula for measuring Heights by the Barometer.—Altitudes are usually estimated by aneroid barometers specially graduated for the purpose and corrected by the use of "Altitude Tables."

If mercurial instruments are employed simultaneous readings should be taken at sea-level and at the higher altitude. The method is similar to the one for reduction to sea-level.

Example.—Sea-level reading = 31.5 inches.
Reading at higher altitude = 28.4 inches.
Difference = 3.1 inches.

Height above sea-level: $1 : 3.1 :: 900 : x$. $x = 2790$ feet.

Strachan's Formula.—This necessitates the use of an aneroid barometer. Take the upper and lower readings in inches, tenths, and hundredths of an inch (*i.e.*, to two decimal places), subtract one from the other and treat the result as if it consisted *entirely of whole* numbers (move the decimal point two places to the right, *i.e.*, multiply by 100, converting decimals into whole numbers), and multiply by 9; the result gives the required height in feet.

Example.—Reading at lower level = 32.53 inches.
" " upper " = 28.41 "
Difference = 4.12. Take 4.12 as 412 (no decimals).
$\therefore 412 \times 9 = 3708$ feet = altitude above sea-level.

The Vernier (Figs. 11 and 12).—The length and subdivisions of the Vernier-scale are in relation to the fixed scale of the barometer.

The scale on the barometer is divided into:

inches and half-inches.

tenths of an inch $= \frac{1}{10} = 0.1$ inch,

half-tenths of an inch $= \frac{1}{20} = 0.05$ inch,

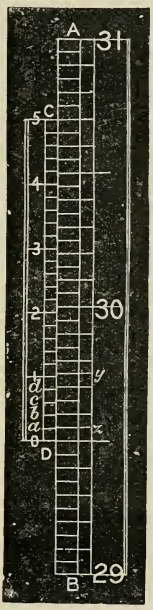

FIG. 11.—Vernier.

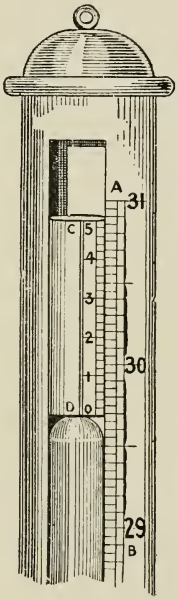

FIG. 12.—Vernier.

which form the smallest divisions on the barometer scale; and twenty-four of them are equal to $0.05 \times 24 = 1.2$ inch.

The Vernier-scale has 5 large divisions, each of which is subdivided into 5, making 25 in all. These 25 are equal in length to 24 of the 0.5 inch divisions of the fixed scale, and are therefore equal to 1.2 inch in length, so that each small division equals $\frac{1 \cdot 2}{2 5}$, or 0.048 inch, and one large division on the Vernier-scale $= 5 \times 0.048 = 0.24$ inch.

The *difference* between the smallest divisions on the two scales is equal to $0.05 - 0.048 = 0.002$ inch; therefore each small division

on the Vernier is 0.002 inch smaller than that on the fixed scale, and each of the larger Vernier divisions indicates a *difference* of $5 \times 0.002 = 0.01$ inch. A longer line placed at these points is marked 1, 2, 3, 4, and 5, corresponding to 0.01, 0.02, &c., or hundredths of an inch.

To take a reading (after noting the temperature of the *attached* thermometer and adjusting the cistern-level, &c.), bring the lowest (zero-) line of the Vernier exactly on a level with the top of the mercurial column ("tangential" to the convex surface). If it is on a line with one of the divisions on the fixed scale, read off the height on the latter only, the Vernier-scale is not required.

If the mercury-level lies between two of the smallest divisions of the *fixed* scale, adjust the Vernier as before, read off the height on the fixed scale in inches, 0.1 inch, and to the nearest 0.05 inch which lies *immediately below* the top of the column.

Next follow up the smallest divisions on the Vernier-scale until one of them is found exactly level with a line on the fixed scale. (1) Count how many of these small Vernier divisions intervene between the zero-line (level with the mercury) and that on the fixed scale, multiply them by 0.002 inch, and add the result to the partial reading already obtained on the fixed scale. (2) The figures on the Vernier may be utilised instead of the above method: Note the Vernier figure ("1," "2," "3," or "4,") immediately below the "junction" of the scale-lines, and consider it as 0.01, 0.02, 0.03, or 0.04 inch and add it to the reading of the fixed scale. Multiply any smaller divisions lying between *this point and the "junction"* by 0.002 and add the result, the total of these three readings is the correct one, and will be the same as that obtained by the first method (1).

Example.—Fig. 11. Zero-line of Vernier is level with top of mercurial column and also with line of fixed scale. The reading is taken entirely by the latter, the Vernier is unnecessary.

Reading: 29.5.

Fig. 12. I. *Reading by fixed scale:* 29.6 (inch- and 0.1 inch-divisions).

" " " " 0 05 (immediately below top of column).

II. *Reading by Vernier-scale:* (1) 17 small divisions intervene between the zero-line of the Vernier and the "junction" line (level with one on the fixed scale): $17 \times 0.002 = 0.034$ inch.

Therefore 29.6
0.05
0.034

Correct reading = 29.684 inches.

(2) Instead of reading as above: Note that in Fig. 12 the figure "3" on the Vernier-scale is immediately below the "junction"; this represents 0.03 inch. Between this point and the "junction" there are two small divisions; therefore $2 \times 0.002 = 0.004$.

We have therefore by fixed scale: 29.6
0.05
„ Vernier-scale: 0.03
0.004
Correct reading = 29.684 (as above).

Temperature.—British Method. F.° scale.

I. One observation daily, 9 A.M.

E.g. On Feb. 21 at 9 A.M. Maximum registered 43.5° F.
Minimum „ − 29.0° F.

Maximum reading = maximum temperature of *previous afternoon*
Minimum „ = minimum „ „ same morning
i.e. "February 20 (afternoon) = 43.5° F.
„ 21 (morning) = − 29.0° F."

Daily mean temperature:

II. (1) Two observations daily, 9 A.M. = 58.6, 9 P.M. = 46.5 $\Big\}$ $\frac{105.1}{2} = 52.5°$ F. = daily mean.

(2) Or shade maximum $\left\{\begin{matrix}=60.0\\=59.2\end{matrix}\right\}$, „ minimum $\left\{\begin{matrix}=45.0\\=43.5\end{matrix}\right\}$ $\Big\}$ $\frac{207.7}{4} = 51.9$ = daily mean.

III. Three observations daily, 6 A.M. = 42.5° F., 2 P.M. = 48.0°, 10 P.M. = 32.2° $\Big\}$ $\frac{122.7}{3} = 40.9$ daily mean.

Continental Method. C.° scale. *Three* observations at 8 A.M. 2 and 10 P.M. marked + and − if respectively above and below 0° C. The results are added algebraically (subtracting − signs) and the 10 P.M. observation is doubled, *i.e.*, *added twice*, and the total result is divided by 4. *E.g.*:

8 A.M. = − 6° C., 2 P.M. = + 5°, (Twice) 10 P.M. = + 3, 10 P.M. = + 3 $\Big\}$ 11 − 6 = + 5. $\frac{5}{4}$ = + 1.25° C. daily mean temperature.

$$\text{Monthly mean temperature} = \frac{\text{Sum of the daily means}}{\text{Number of days in the month}}$$

$$\text{Annual „ „} = \frac{\text{Sum of monthly means}}{12}$$

Daily range or amplitude of temperature:

Shade maximum – Shade minimum temperature for that day.

$$\text{Monthly mean range:} \frac{\text{Sum of the daily ranges}}{\text{Number of days in the month}}$$

or,

$$\frac{\text{Daily maxima of month} - \text{Daily minima of month}}{\text{Number of days in month}}$$

$$\text{Yearly mean range:} \frac{\text{Sum of monthly mean ranges}}{12}$$

or,

$$\frac{\text{Daily maxima of year} - \text{Daily minima of year}}{365}$$

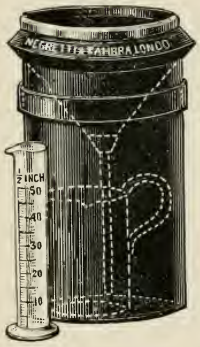

Fig. 13.—Rain-gauge.

Solar radiation: Sun-maximum – Shade maximum temperature.

Better: Sun maximum *minus* open-air temperature taken when the sun-maximum thermometer is at its highest point.

Terrestrial radiation = Shade minimum – "grass minimum" reading.

Graduation of the Measuring-Glass of a Rain-Gauge.—The usual diameters of the rim of the rain-gauges (Fig. 13) used in this country are 5 (Symons' "Snowdon") and 8 inches (Glaisher's). The latter diameter is used by the Meteorological Office and by the British Association.

Let D = diameter in inches. R = radius.

$D = 2\ R.$

C = circumference of rim.

$\pi = 3.1416$ (ratio of circumference to diameter $= \frac{22}{7}$).

$C = 2\ \pi R.$ Area of circle $= \pi R^2$.

If D = 5 inches.

$$\text{Area of receiving-surface of rain-gauge} = 3.1416 \times (2.5)^2$$
$$= 3.1416 \times 6.25$$
$$= 19.635 \text{ sq. inches.}$$

One inch of rainfall on this area = 19 635 × 1 = 19.635 cubic inches, or half an inch of rainfall = 9.8175 cubic inches.

1.73 cubic inch = 1 fluid ounce, ∴ 9.8175 cubic inches = 5.675 ounces of rain. If this amount of water be poured into a non-graduated measure-glass and the level marked with a line, it will represent the height of half (0.5) an inch of rainfall on the receiving

area of the gauge. This height on the glass is subdivided into 50 equal parts, and each denotes $\frac{1}{50}$ of $\frac{1}{2}$ inch, or 0.02×0.5 inch of rain $= 0.01$, or one-hundredth of an inch. The amount collected when poured into the measure-glass can at once be read off in decimals of an inch. If $D = 8$ inches, area $= 3.1416 \times (4)^2 = 50.2656$ square inches $= 14.5$ ounces nearly ($\frac{1}{2}$ in. of rainfall). The subdivisions are made as before.

An area of any known dimensions will do for collecting the rain and graduating a glass. Conversely, if the amount of water required to represent half an inch of rainfall is stated, the necessary diameter of the rain-gauge can be calculated.

Example.—One ounce of water in the measure-glass is required to denote half an inch of rainfall. What must be the diameter of the rim?

Area of receiving surface enclosed by the rim $= \pi R^2$, and this area when covered with half an inch of rainfall must equal 1 fluid ounce, *i.e.*, 1.73 cubic inches.

$$\therefore\ 3.1416 \times R^2 \times 0.5 = 1.73. \qquad R^2 = \frac{1.73}{3.1416 \times 0.5} = 1.113$$

$$R = \sqrt{1.113} = 1.055 \text{ inch (nearly)}$$

$$\therefore\ D = 2R = 2.11 \text{ inches.}$$

The diameter of the rim must be 2.11 inches and the surface-area will be 3.49 square inches.

Velocity of the Wind.—The anemometer named after the Rev. Dr. Robinson of Armagh is in general use. The length of the arms measured from the centres of opposite cups varies from 1.12 feet to 2 feet.

In the first case 1.12 feet is the diameter of the circle described by the centre of each cup as it revolves.

$\therefore$ Circumference $= 2\pi R = \pi \times$ diameter $= 3.1416 \times 1.12 = 3.52$ feet.

If the cups are considered to revolve at one-third the velocity of the wind, wind-velocity $= 3.52 \times 3 = 10.56$ feet per each revolution, and to calculate the number of rotations per mile:

$$10.56 : 5280 :: 1 : x. \qquad x = 500 \text{ revolutions.}$$

Symons (in Stephenson and Murphy's *Treatise*) considers the velocity of the wind to be 2.5 times greater than that of the cups,

$\therefore\ 3.52 \times 2.5 = 8.8$ feet per revolution, and the number of revolutions per mile $= 600$.

Using 2.5 as the factor, with a diameter of 2 feet the circumference of the circle is 6.28 feet, the wind-velocity 15.7 feet per revolution, there being 336.3 rotations per mile.

The records are not accurate, as the velocity varies with the

length of the arms, being below the mark with short, and above it with long arms.

Pressure of the Wind.—Pressure varies as the square of the velocity.

Col. H. James' Formula:

Let P = pressure in pounds per square foot.
V = velocity of wind in miles per hour.

$$V = \sqrt{200\ P}. \quad V^2 = 200\ P. \quad P = \frac{V^2}{200} = V^2 \times \frac{1}{200} = V^2 \times 0.005.$$

Example.—(1) Pressure in pounds per square foot = 15.25.

$$V^2 = 200 \times 15.25 = 3050.$$
$$V = \sqrt{3050} = 55.22 \text{ miles per hour.}$$

(2) Velocity of wind = 86.8 miles per hour.
$P = (86.8)^2 \times 0.005 = 37.67$, or 37.7 pounds per square foot.

Note.—(Velocity in feet per second)$^2 \times 0.0023$ = Pressure in pounds per square foot (approximately).

Example (1) as above: $\frac{55.22 \times 5280}{60 \times 60} = 80.96$ feet per second.

$(80.96)^2 \times 0.0023 = 15.075$, or nearly 15.25 pounds per sq. ft.

CHAPTER IV.

VENTILATION.

Respiration.—Pure air contains on an average :

Oxygen	20.94
Hydrogen	0.02
Nitrogen	78.00
Argon, metargon, &c.	1.00
Carbon dioxide	0.04*
	100.00

Expired air contains on an average 16 per cent. of oxygen and 4.4 per cent. of CO_2.

Amount of CO_2 exhaled at each breath in excess of that contained in the air $= 4.4 - 0.04 = 4.36$ *per cent.* An adult male breathes about 18 times per minute, and the tidal air averages about 25 cubic inches (500 c.c.). Amount of CO_2 expired at each breath :

$$100 : 25 :: 4.36 : x. \quad x = 1.09 \text{ cubic inch } (21.8 \text{ c.c.})$$

Per minute $= 1.09 \times 18 = 19.62$ cubic inch (392.4 c.c.) of CO_2
„ hour $= 1177.2$ cubic inches, or nearly 0.7 cubic foot.

Parkes and de Chaumont adopted 0.6 cubic foot per individual per hour as the average amount of CO_2 exhaled in a "mixed community," *i.e.*, of adults and children.

Velocity of Inflow and Outflow of Air. — Velocity $= \frac{\text{Volume of air}}{\text{Sectional area of aperture}} =$ The "terms" must be of the same "denomination," *i.e.*, to calculate a velocity in linear feet the volume must be expressed as cubic feet and the sectional area in square feet. If the latter is stated in square inches these must be converted into square feet.

E.g., Velocity in linear feet $= \frac{\text{Flow in cubic feet}}{\text{Sectional area in square feet}}$.

* According to some investigators the average amount of CO_2 in pure air is but little over 0.3 per cent., or 3 parts in 10,000 by volume.

Example.—(1) An outlet of 48 square inches sectional area delivers 12,000 cubic feet per hour. Estimate the velocity of outflow in feet per minute and per second.

$$\text{Velocity in linear feet} = \frac{1200}{\frac{48}{144}} = 4000 \text{ feet} = \frac{4000}{60} = 66.6 \text{ per}$$

minute, and $\frac{66.6}{60} = 1.11$ feet per second. If $\frac{1}{4}$ be deducted for friction $1.11 - \frac{1.11}{4}$ $(= 1.11 \times 0.75) = 0.83$ feet per second.

(2) To find the velocity required to deliver 3000 cubic feet of air per hour through an inlet of 25 square inches.

$$V = \frac{3000}{\frac{25}{144}} = 3000 \times \frac{144}{25} = 17280 \text{ feet per hour}$$

$$= \frac{17280}{60 \times 60} = 4.8 \text{ feet per } 1''.$$

$$\text{Deducting } \tfrac{1}{4} \text{ for friction : } \frac{4.8}{4} = 1.2$$

$$\therefore\ 4.8 - 1.2 = 3.6 \text{ feet per } 1''.$$

Friction at every right angle diminishes the velocity by $\frac{1}{2}$.

∴ With 2 right angles velocity $= \frac{1}{4}$.

(3) The velocity of inflow is 3 feet per second, and the aperture has a sectional area of 36 square inches. Calculate the volume of air entering per hour.

$$\text{Velocity} = 3 \text{ feet per second.} \quad \text{Area} = \frac{36}{144} = \tfrac{1}{4} \text{ square foot.}$$

Let volume of in-coming air $= x$. $\therefore\ 3 = \frac{x}{\frac{1}{4}}$. $\therefore\ x = \frac{3}{4}$ cubic foot per *second.*

$$= \tfrac{3}{4} \times 60 \times 60 = 2700 \text{ cubic feet per hour.}$$

(4) In a ward for 30 beds it is desired to supply 4000 cubic feet of air per head per hour at a velocity of $2\frac{1}{2}$ feet per second. Estimate the size of inlet required.

As the velocity is given "per second" and the volume of air supply is to be estimated "per hour," the velocity must also be expressed "per hour."

$V = 2.5 \times 60 \times 60$ linear feet per hour.

Total inflow $= 4000 \times 30$ cubic feet per hour.

Sectional area in cubic feet $= x$.

$$\therefore\ 2.5 \times 60 \times 60 = \frac{4000 \times 30}{x}.$$

$2.5 \times 60 \times 60x = 4000 \times 30$. $x = 13.3$ square feet $= 1915.2$ square inches.

For 30 patients $= 63.84$ square inches per head.

Therefore 30 inlets each of 63.84 square inches will suffice, or 60 inlets each of 31.92 square inches.

Supply of Fresh Air.—De Chaumont estimated that 0.02 per cent., or 0.2 per 1000 volumes of CO_2, should represent the maximum amount of respiratory impurity in excess of that existing in pure (external) air. As pure air contains 0.4 volume of CO_2 per 1000, $0.4 + 0.2 = 0.6$ volume of total CO_2 permissible in 1000 volumes of air in a room. This 0.6 per 1000 volumes must not be confused with the 0.6 cubic foot of CO_2 exhaled per individual per hour in a "mixed community."

0.2 cubic foot of added respiratory impurity per 1000 cubic feet $= 0.0002$ per 1 cubic foot of air. If 0.7 cubic foot = amount of CO_2 exhaled per male adult per hour, the calculation for estimating the supply of fresh air needed per hour is:

$0.0002 : 0.7 :: 1 : x$. $x = \frac{0.7}{0.0002} = 3500$ cb. ft. If instead of 0.7 we take 0.72. $x = \frac{0.72}{0.0002} = 3600$ cb. ft., or 1 cb. foot per second —a convenient standard.

Let S = supply of fresh air necessary per hour in cubic feet.
E = amount of CO_2 exhaled per individual per hour.
I = excess of CO_2 permissible (impurity) per 1 cubic foot per hour.

$$\therefore\ S = \frac{E}{I}.$$

De Chaumont's Formula.—De Chaumont considered 0.6 cubic foot CO_2 exhaled per individual per hour as a fair estimate in an assemblage of men, women and children, so that $S = \frac{0.6}{0.0002} = 3000$ cubic feet of fresh air required per person per hour.

The above estimates are for individuals *at rest*

If a man is doing *light* work, $E = 0.9$. $S = \frac{0.9}{0.0002} = 4500$ cb. ft.

„ „ *hard* „ $E = 1.8$. $S = \frac{1.8}{0.0002} = 9000$ „

Large supplies of fresh air necessitate large buildings or increased velocity of inflow, and augment the cost. In most cases this

cannot be done. In a General Hospital the increase is roughly about $\frac{1}{4}$ more than in health: for a male ward E may be taken as = 0.9 (as above) and S = 4500 cubic feet. For a female ward E = 0.8. S = 4000 cubic feet. In schools E = 0.4. $S = \frac{0.4}{0.0002} = 2000$ cubic feet.

If I = CO_2 added as impurity *per 1000 cubic feet of air* (instead of per 1 cubic foot).

$$S = \frac{E}{I} \times 1000 = \frac{0.6}{0.2} \times 1000 = 3000 \text{ cubic feet.}$$

Let E = 0.6 cubic foot of CO_2 expired per individual per hour.
0.4 = CO_2 present in 1000 cubic feet of fresh (external) air.
I = total CO_2 in 1000 cubic feet of air in room *minus* 0.4.
P = number of persons occupying the room (exhaling 0.6 cubic feet of CO_2 per head per hour).
H = number of hours they occupy the room.
S = supply of air for P persons during H hours:

$$S = \frac{0.6 \times P \times H}{I\ (\textit{Total } CO_2 \text{ in 1000 cb. ft. of air in room} - 0.4)} \times 1000.$$

Any one term of this equation can be calculated if the others are known.

Example.—(1) 5 men work for 8 hours in a room containing 6500 cubic feet of air. The total supply of fresh air per hour is 12,000 cubic feet. Calculate the total amount of CO_2 present in the air of the room at the end of that period and also the amount of impurity added as CO_2.

Total air supply for 5 men for 8 hours:
Pure air originally in the room = 6500 cubic feet.
Additional air supplied during 8 hours = 12,000 × 8 = 96,000 cubic feet.

$$6500 + 96000 = 102{,}500 \text{ cubic feet} = S.$$

Each man expires (say) 0.9 cubic foot CO_2 per hour = E.
x = CO_2 per 1000 cubic feet in room after 8 hours $\therefore$ I = x − 0.4.

$$\therefore\ 102{,}500 = \frac{0.9 \times 5 \times 8}{x - 0.4} \times 1000.$$

$$102.5 \times (x - 0.4) = 0.9 \times 5 \times 8.$$

$$102.5x - 41 = 36. \quad 102.5x = 77.$$

$$x = 0.75 \text{ ft. } CO_2 \text{ per } 1000 = 0.075 \text{ per cent.}$$

Added impurity (I) = 0.75 − 0.4 = 0.35 per 1000, or 0.035 per cent. It should not exceed 0.2 per 1000 according to de Chaumont's formula, therefore there is an excess of 0.35 − 0.2 = 0.15 per 1000.

Carnelley's Formula.—Carnelley, Haldane and Anderson allowed a larger excess of CO_2 than de Chaumont did, as follows:

(1) For dwelling-houses 0.6 vol. of CO_2 per 1000 *in excess of that in fresh air.*

(2) For schools 0.9 vol. of CO_2 per 1000 *in excess of that in fresh air.*

As fresh (pure) air contains 0.4 vol. CO_2 per 1000, – the *total* CO_2 allowable for (1) dwellings and (2) schools is $0.6 + 0.4 = 1.0$ per 1000; and $0.9 + 0.4 = 1.3$ per 1000, respectively.

$\therefore$ I for (1) $= 1.0 - 0.4 = 0.6$ *added impurity* per 1000 cubic feet $= 0.0006$ per 1 cubic foot.

for (2) $= 1.3 - 0.4 = 0.9$ *added impurity* per 1000 cubic feet $= 0.0009$ per 1 cubic foot.

(1) $E = 0.6$.

$$\therefore S = \frac{0.6}{.0006} = 1000 \text{ (houses)}.$$

(2) $E = 0.4$.

$$S = \frac{0.4}{0.0009} = 444 \text{ (schools)}.$$

If $E = 0.45$. $S = \frac{0.45}{0.0009} = 500$ (schools). The latter figure is preferable, as allowance must be made for the adult staff of the school.

Example.—(2) A male ward in a General Hospital has an hourly supply of 112,500 cubic feet of fresh air. The atmosphere of the ward must not contain more than a total amount of 0.06 CO_2 per 100 cubic feet. How many beds should there be?

S = 112,500 cubic feet per hour.

E = 0.9 cubic foot, CO_2 per head per hour (male cases).

I = 0.6 – 0.4 (pure air) = 0.2 per 1000 cubic feet of ward atmosphere.

P = is to be calculated.

H = 1 hour.

$$\therefore 112{,}500 = \frac{0.9 \times P \times 1}{0.2} \times 1000.$$

$$112.5 = \frac{0.9\,P}{2}. \quad 225 = 9\,P. \quad P = 25.$$

There should be accommodation for 25 male patients.

(Note.—The air originally present in the ward is omitted.)

Example.—(3) In a school 65 children work for 5 hours, and the air at the end of that time is found to contain 0.13 per cent. of CO_2. Find how much air is supplied during the entire period, and also per individual per hour.

Taking E as 0.45 cubic foot CO_2 evolved per head per hour.
P = 65. H = 5. 0.13 per cent. = 1.3 per thousand.
$\therefore$ I = 1.3 − 0.4 CO_2 = added impurity per 1000 cubic feet of air in schoolroom.
S is to be found:

$$\therefore S = \frac{0.45 \times 65 \times 5}{1.3 - 0.4} \times 1000.$$

$$= \frac{146.25}{0.9} \times 1000.$$

= 162,500 feet per head during 5 hours; 32,500 cubic feet per hour, or 500 cubic feet per individual per hour.

According to Carnelley's estimate this is satisfactory; by de Chaumont's standard of 2000 cubic feet per child per hour it is 2000 − 500 = 1500 below the proper supply.

Example.—In a room 20 feet long, 14 wide, and 12 feet high, 5 clerks work, using 3 ordinary gas-burners. How much air is required for proper ventilation?

Gas used per burner = 4 cubic feet per hour.
= 12 cubic feet per 3 hours.
1 cubic foot of gas = 0.5 cubic foot CO_2.
4 „ feet „ = 2.0 „ feet „
12 „ „ „ = 6.0 „ „ „

Taking 0.7 cubic foot CO_2 as exhaled per man per hour.
3.5 „ feet „ is „ „ 5 men „
6.0 + 3.5 = 9.5 CO_2 in the room per hour.

$$S = \frac{9.5 \times 1000}{0.2} = 47{,}500 \text{ cubic feet.}$$

The room originally contained 20 × 14 × 12 = 3360 cubic feet of fresh air (not allowing for furniture, &c.)

$\therefore$ 47,500 − 3360 = 44,140 cubic feet in addition to that originally in the room should be supplied during the first hour of occupation, and for every subsequent hour (after the 3360 cubic feet are exhausted) 47,500 cubic feet of fresh air are necessary.

Example.—(4) A room 20 feet long, 12 feet broad, and 10 feet high is occupied by two adults and a child under six years of age. If there is practically *no ventilation*, when will the limit of permissible impurity be reached?

S = 20 × 12 × 10 = 2400 cb. ft. fresh air originally in the room.
E = 0.6 cb. ft. CO_2 per head per hour ("mixed community.)"
Two adults and one child = 2.5 adults.
∴ P = 2.5. H is to be calculated.
Total impurity = 0.6 cubic foot CO_2 per 1000 cubic feet.
I = 0.6 − 0.4 = 0.2 cubic foot per 1000.

$$\therefore\ 2400 = \frac{0.6 \times 2.5 \times H}{0.2} \times 1000.$$

$$2.4 = \frac{1.5\ H}{0.2}.\quad 4.8 = 15\ H.\quad H = 0.32 \text{ of an hour.}$$

$$= 19.2 \text{ minutes.}$$

By Carnelley's formula: $2.4 = \frac{1.5\ H}{0.6} = H = 0.96$ of an hour.

$$= 57.6 \text{ minutes.}$$

Fresh Air Supply for Horses and Cattle.—These animals are not affected by a rapid current of air or a low temperature if well stabled.

De Chaumont's formula may be adopted.

A horse exhales 1.13 cubic feet CO_2 per hour.

Taking "I" as 0.6 − 0.4 = 0.2 cubic foot per 1000 as "*added* impurity": $S = \frac{1.13}{0.2} = 5650$ cubic feet fresh air supply per hour.

The same ratio may be used for large cattle.

Natural Ventilation.—The velocity acquired by a body falling through space is proportional to the time it takes in falling. Its "acceleration" is due to gravity, which causes a velocity of fall equal to 32.2 (taken as 32.0) feet per second in this latitude, and the motion is *uniformly accelerated*, 32 being a constant "factor."

Let V = velocity of fall in feet per second.
G = "acceleration" = 32 feet per second.
T = time of fall in seconds.
V = G × T.
= 32 × T.

If a body falls (from a state of rest) for three seconds:
V = 32 × 3 = 96 feet per second *at the end of three seconds.*

If the "height" or distance through which a body has fallen be known, its final velocity in feet per second is equal to eight times the square root of the distance traversed.

Let H = height (distance) of fall.

$\therefore V^2 = 2G \times H. \quad G = 32. \quad \therefore V^2 = 2 \times 32 \times H.$

$V = \sqrt{2 \times 32 \times H.}$

$= \sqrt{64 \times H.}$

$= 8\sqrt{H.}$

By Montgolfier's law, air and other fluid media pass through an opening in a partition with the same velocity as a body falling through a height equal to the difference in level of the fluids on each side of the partition. This difference in level is "head."

Air rushes into a vacuum (resistance at first is *nil*) at the same velocity as a body falling from a height of five miles or 26,333 feet.

$\therefore V = \sqrt{2 \times 32 \times 26333} = 8\sqrt{26333} = 1296$ feet per second.

As air passes into a vacuum, the internal pressure (being zero at first) gradually increases with increase of air volume, and its decreasing velocity would be equal to that of a body falling through diminishing heights representing differences of pressure inside and outside the chamber. These varying differences in height and pressure (*i.e.*, weight) cannot be calculated, and are estimated approximately by *differences in temperature* of the inside and outside air.

Difference in pressure = difference in height of inlet and outlet (= height of heated column of air) × difference of temperature × coefficient of expansion of air.

Let H = height of heated column of air in the flue (or vertical distance between inlet and outlet).

„ T = temperature (Fahrenheit) of inner air.

„ t = „ „ „ outer „

0.002 ($= \frac{1}{491}$ approximately) = coefficient of expansion of air per 1° F.). V = velocity in linear feet per second.

Difference in pressure = $H \times (T - t) \times 0.002$.

$\therefore V = 8\sqrt{H \times (T - t) \times 0.002}$.

Example.—The external opening of a ventilating shaft is 22 feet above the internal aperture. The temperature of the room is 60° F. and that of the external air 47.2° F. Calculate the velocity of the current of air up the shaft.

$H = 22$ feet. $T - t = 60 - 47.2 = 12.8$.

$V = 8\sqrt{22 \times 12.8 \times 0.002}$.

$= 8\sqrt{0.5476}$.

$= 8 \times 0.74 = 5.92$ feet per second.

Deducting $\frac{1}{4}$ for loss of velocity due to friction (which is the same as multiplying by 0.75) $5.92 \times 0.75 = 4.44$ feet per second.

De Chaumont's Modification of this Formula for calculating the Size of Inlet or Outlet, or the Quantity of Air Supply per Hour.

Let S = supply of air in *cubic feet* per hour.
A = area of *inlet or outlet* in *square inches.*
H = height of heated column of air.
T = temperature of room or of air-column.
t = „ „ external atmosphere.

$$S = \left(8 \times \frac{\text{seconds in 1 hr.}}{\text{sq. in. in 1 sq. ft.}}\right) \times A \times \sqrt{H \times (T - t) \times 0.002 \times 0.75}.$$

$$S = 200 \times A \times \sqrt{H \times (T - t) \times 0.002 \times 0.75}.$$

Example.—(1) The difference in height between inlet and outlet is 25 feet. The inner and outer mean temperatures are 65° F. and 45° F. respectively, and the air supply is 3000 cubic feet per hour. Estimate the size of the inlet.

$S = 3000$. $T - t = 20$. $3000 = 200 \times A \times \sqrt{25 \times 20 \times 0.002} \times 0.75$.

$= 200\ A \times 5 \times 0.2 \times 0.75$.

$A = 11.25$ square inches.

According to Parkes and de Chaumont the dimensions of the outlet may correspond with those of the inlet, the increase in volume of air that has been warmed is so small ($\frac{1}{50}$ to $\frac{1}{16}$) under the usual conditions of ventilation and heating that it may be neglected.

The size of inlets and outlets per individual in health may be approximately estimated as follows:

Let n = number of adults to be supplied (from 1 to 6 *as a maximum*) by one aperture.

∴ Area of aperture = $12 \times 2n$ square inches, therefore:

For 1 adult	„	„	„ × 2 =	24	square inches.
„ 2 adults	„	„	„ × 4 =	48	„ „
„ 2 adults and 1 child	„	„	„ × 5 =	60	„ $\left(\text{child} = \frac{n}{2}\right)$
„ 3	„	„	„	„ × 6 =	72	„ „
„ 6	„	„	„	„ × 12 =	144	„ „

At temperatures between 55° and 60° F., a velocity of

1.5 linear ft. per sec. is not perceived
2 – 2.5 „ „ „ „ „ by most people.
3 „ „ „ felt „ „
3.5 „ „ „ „ by all and causes a draught.

(*Parkes and de Chaumont.*)

3000 cubic feet per hour = 50 cubic feet per minute = 0.83 cubic foot per second.

Velocity of air current (linear feet)

$$= \frac{\text{Inflow (cubic feet)}}{\text{Sectional area of inlet (square feet)}}.$$

Inlet = 24 square inches. Inflow = 0.83 cub. ft. per sec.

$$\text{Velocity} = \frac{0.83}{\frac{24}{144}} = 4.98 \text{ lin. ft. per sec.}$$

Inlet = 48 square inches. " " " "

$$\text{Velocity} = \frac{0.83}{\frac{48}{144}} = 2.49 \text{ lin. ft. per sec.}$$

Inlet = 60 square inches. " " " "

Velocity = 1.99 (2.0) lin. ft. per sec.

Inlet = 72 square inches. " " " "

Velocity = 1.66 lin. ft. per sec.

Inlet = 144 square inches. " " " "

Velocity = 0.83 lin. ft. per sec.

The inlets of 48 to 72 square inches give the best velocity for a supply *per head* of 3000 cubic feet per hour.

Parkes and de Chaumont considered the minimum and maximum sizes should be 24 and 144 square inches, and that for larger supplies of air the *number* of openings must be proportionally increased and *not their size*. This method facilitates uniform distribution of air per person, and diminishes liability to draughts or to areas of "stagnation."

Example.—(2) A heated column of air 40 feet in height has an average temperature of 60° F., the air outside being at 32° F. The area of inlet equals that of outlet, and is 72 square inches. Calculate the supply of air passing in, and the velocity of outflow.

$T - t = 60 - 32 = 28.$

$S = 200 \times 72 \times \sqrt{40 \times 28 \times 0.002} \times 0.75.$

$= 200 \times 72 \times \sqrt{2.24} \times 0.75.$

$= 200 \times 72 \times 1.5 \times 0.75.$

$= 16{,}200$ cubic feet per hour $= \frac{16{,}200}{60} = 270$ per minute, or

$\frac{270}{60} = 4.5$ cubic feet per second.

To find the velocity of outflow in linear feet per second:

$$\text{Velocity} = \frac{\text{Outflow in cubic feet per second}}{\text{Sectional area of inlet in square feet}}.$$

$$= \frac{4.5}{\frac{72}{144}} = \frac{4.5}{\frac{1}{2}} = 9 \text{ linear feet per second.}$$

Natural Ventilation by Diffusion of Air.—It occurs only in gases and vapours and does not affect molecular matter. The rate of diffusion is inversely proportional to the square root of the density.

The density of hydrogen = 1 $\therefore \frac{1}{\sqrt{1}} = 1$. Rate of diffusion of oxygen $\frac{1}{\sqrt{16}} = \frac{1}{4}$. = 4 times greater than that of hydrogen.

Rate of diffusion of nitrogen =

$\frac{1}{\sqrt{14}} = \frac{1}{3.74} = 3.74$ times . „ „ „

Rate of diffusion of air =

$\frac{1}{\sqrt{14.44}} = \frac{1}{3.8} = 3.8$ times „ „ „

Calculation of Friction in Ventilation.—It is determined by the length of the shaft, its angles, and by the dimensions and shape of the aperture through which the air current passes.

Length.—If the tube or shaft is of uniform bore throughout, friction increases in direct proportion to increase in length.

EXAMPLE (1).—Shaft A = 100 feet in length } uniform bore.
„ B = 120 „ „ „ }

The friction in B is $\frac{1}{5}$ more than in A.

Angles.—Every bend of 90° diminishes the velocity of the current by half—*e.g.*, a velocity of 10 linear feet will be after the first right-angle bend = 5 feet, and after the second bend = $\frac{1}{2}$ of 5 feet = $2\frac{1}{2}$ feet, and after a third similar angle = $\frac{1}{2}$ of $2\frac{1}{2} = 1\frac{1}{4}$ linear feet. This is theoretical only, as after two such bends in a pipe ventilation is practically *nil* for hygienic requirements. Friction at other angles is calculated by Trigonometrical factors.

Dimensions and Shape of Apertures.—A. Loss by friction varies inversely as the diagonal or diameter.

The openings are of similar shape:

(*a*) Squares.

EXAMPLE.—A square aperture ABCD is subdivided into 4 smaller squares of equal size. Calculate the friction in each of these compared with that in the larger opening (*vide* p. 62).

Diagonal of ABCD = AC or BD.
„ „ each small square = $\frac{1}{2}$ AC or BD.

If friction in ABCD = 1.
$\therefore$ friction in each small square = 2.
i.e. it is twice that in ABCD.

(*b*) Circles.

Example.—Two circular apertures have diameters of 1 foot and 4 inches respectively. Estimate the friction in the smaller relative to that in the larger.

The larger diameter = 12 inches.

„ smaller „ = 4 „ The ratio of the latter to the former is as 4 to 12 or as 1 to 3.

If the friction in the smaller circle = 1.

∴ „ „ „ larger = $\frac{1}{3}$. It is 3 times less than that of the smaller aperture.

B. Loss by friction varies inversely as the square roots of the areas, whether the openings are of similar or dissimilar shape.

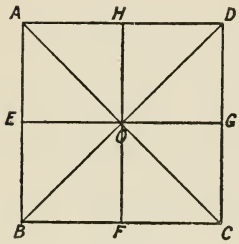

Fig. 14.

Supposing the square ABCD has its sides 1 foot in length, its area is 144 square inches.

Each smaller square has an area of 36 square inches, $\sqrt{36} = 6$, $\sqrt{144} = 12$: a ratio of 1 to 2.

The loss by friction in the smaller aperture is twice that in the larger one.

If a circular inlet has an area of 9 square feet and a square aperture an area of 4 square feet, $\sqrt{9} = 3$. $\sqrt{4} = 2$.

The loss by friction in the former to the latter is as $\frac{1}{3}$ to $\frac{1}{2}$.

The circumference of a circle encloses maximum area in minimum periphery. If the friction in two circular openings is to be contrasted, the calculation is made from the respective diameters, as above.

If the shape is non-circular, ascertain its periphery and the area enclosed. Calculate the length of periphery of a circle enclosing an exactly equal area. The friction in the circular opening is to that in the non-circular one as the periphery of the one is to that of the other.

Example.—A square aperture has its side 14.18 inches long, compare the friction in it to that in a circular opening of equal area.

Area of square aperture = $(14.18)^2 = 201.0724$ square inches.
Periphery „ „ „ = $14.18 \times 4 = 56.72$ linear „
Area of circle = πR^2. $\pi R^2 = 201.0724$ square inches.

$R^2 = \frac{201.0724}{3.1416} = 64$ inches (nearly). $R = \sqrt{64} = 8$ inches.

Circumference = $2\pi R = 2 \times 3.1416 \times 8 = 50.2656$ inches.

Friction in circular opening is to friction in square opening as 50.2656 is to 56.72, or as 1 to 1.12, *i.e.*, the friction in the latter

is a little more than $\frac{1}{8}$th greater, and the velocity is proportionally diminished.

Artificial Ventilation.—1. By an ordinary Fire-place.—In a sitting-room with an open fire-place, the chimney is the usual means of ventilation. Its sectional area may be taken as 1 square foot, and the velocity of the current of air up the flue as 4.5 linear feet per second.

$4.5 \times 1 = 4.5$ cubic feet per second, or $4.5 \times 60 \times 60 = 16{,}200$ cubic feet per hour discharged by the flue.

Each adult requires 3000 cubic feet of fresh air per hour. If 16,200 cubic feet of fresh air per hour replace that amount extracted by the flue, we find by simple proportion:

$$3000 : 16{,}200 :: 1 : x. \quad x = 5 \text{ adults.}$$

So that the ventilation is sufficient for 5 adults occupying the room.

2. By Circular Fans.—The circumference of the circle described in each revolution by the tip of a vane is calculated from the diameter of the fan; and the velocity, from the number of revolutions per second, or per minute.

The tangential velocity of the particles of air leaving the fan is $\frac{3}{4}$ the velocity of the tips of the vanes.

Velocity of the air-current × sectional area of outlet = volume of discharge.

Example.—(1) Diameter of fan = 2.5 feet.
Number of revolutions = 3 per second.
Diameter of outlet = 1 foot.

Calculate the velocity of the air and the volume discharged.

Circumference of circle described by the vanes at one revolution $= 3.1416 \times 2.5 = 7.85$ feet.

Velocity of each vane $= 7.85 \times 3 = 23.55$ feet per second.

„ „ air current $= 23.55 \times \frac{3}{4} = 17.66$ feet per second.

Area of outlet $= \pi \times (\text{radius})^2 = 3.1416 \times (0.5)^2 = 0.7854$ square foot.

Discharge $= 17.66 \times 0.7854 = 13\ 87$ cubic feet per second
$= 49932$ „ „ „ hour.

Example.—(2) 750,000 cubic feet of fresh air are to be supplied per hour. Calculate the diameter of the fan necessary to effect this and the number of revolutions per second, the diameter of the inlet being 2 feet.

Delivery = velocity of air current × area of inlet.

Radius of inlet = 1 foot. ∴ area $= \pi \times 1 = 3.1416$.

∴ 750,000 = velocity of air current × 3.1416.

Velocity of air current $= \frac{750{,}000}{3.1416}$ feet per hour.

$$= \frac{750{,}000}{3.1416 \times 60 \times 60} = \text{per second.}$$

Velocity of each vane $= \frac{750{,}000 \times 4}{3.1416 \times 60 \times 60 \times 3} = 88.4$ feet per second, or distance traversed per second.

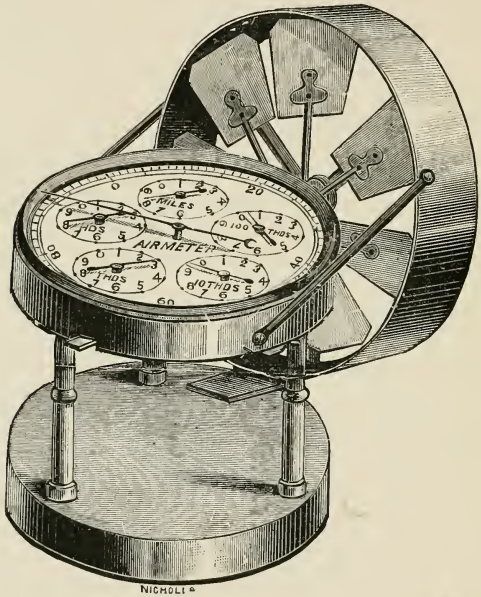

FIG. 15.—Anemometer.

Let D = diameter of fan in feet, and R = number of revolutions per second.

$3.1416 \times D$ = circumference of fan in feet.

$3.1416 \times D \times R$ = distance traversed by a vane in one second.

$\therefore\ 3.1416 \times D \times R = 88.4$ feet.

$\therefore\ D \times R = \frac{88.4}{3.1416} = 28$ feet per second.

$\therefore\ D = \frac{28}{R}.\quad R = \frac{28}{D}.$

If the number of revolutions is 10 per second, D = 2.8 feet.

" " " " 5 " " D = 5.6 "

If the diameter of the fan is 4 feet there must be 7 revolutions per second.

To Calculate the Velocity of the Current of Air and its Volume.—Ascertain: (1) the area of each inlet; (2) the *mean velocity* of the current passing through it; (3) the actual air capacity of the room.

The average of several observations at the periphery and near the centre of the aperture must be taken.

If the opening is circular, note the velocity of the current at a point $\frac{2}{5}$ of the diameter from the side of the shaft.

Mean velocity × area of opening = volume of air.

For greater accuracy the amount of air entering should be checked by estimating the amount of air leaving the room. These should be equal.

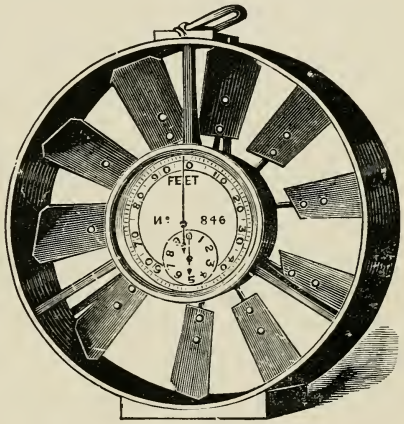

Fig. 16.—Biram's Anemometer.

The Anemometer.—(1) Casella's instrument. The velocity of the rotating vanes is registered by the long hand, recording 50 feet per minute on the large dial divided into 100 feet, and on five small dials showing respectively velocities of 1000, 10,000, 100,000 feet, and miles. The indices are started or stopped by means of a small knob, and can be thrown out of gear without checking the rotation of the vanes. $\frac{\text{Velocity in feet per minute}}{88}$ = velocity in miles per hour.

(*a*) If the indices are not at zero, read off any previous record and deduct this from the reading after the experiment.

(*b*) A "correction" (determined by the instrument-maker) is sent with each instrument, and represents the minimum velocity which will move the vanes. It is to be added to the reading for each observation, and is about 30 feet per minute, or 6 inches per second.

(2) Biram's Anemometer.—In the smaller instruments the vanes rotate on a central axis on which are the index-dials. The larger instruments have a different arrangement.

Example.—The actual air capacity of a room is 1450 cubic feet. Two air inlets, each of 60 square inches, supply air at an average velocity of 2 feet per second. Find the volume delivered per hour and the number of times it is renewed.

Total inlet area $= 2 \times \frac{60}{144} = \frac{5}{6}$ square foot.

Current velocity $= 2 \times 60 \times 60 = 7200$ linear feet per hour.

Amount supplied per hour $= 7200 \times \frac{5}{6} = 6000$ cubic feet.

Air capacity of room $= 1450$ cubic feet.

$\therefore \frac{6000}{1450} = 4.14$ nearly, *i.e.*, the atmosphere of the room is completely changed a little more than four times an hour. In a small room, unless the current is well divided and properly warmed, it will cause a draught.

Example.—Air-meter registers 2546 linear feet from previous observations. Placed in ventilating shaft $\frac{2}{3}$ distance from side it indicates "3746" linear feet in 5 minutes.

Sectional area of shaft $= 1.6$ square foot. Correction for instrument $= 30$ linear feet per minute *additive*.

$3746 - 2546 = 1200$ linear feet in 5 minutes.

Adding correction $(30 \times 5) = 1350$ linear feet in 5 minutes or 4.5 linear feet per second.

$1.6 \times 4.5 = 7.2$ cubic feet per second, or 25,920 cubic feet per hour.

Estimation of Superficial and Cubic Space.

Superficial measurement of:

Square $= (\text{side})^2$.

Rectangle $=$ length $\times$ width.

Triangle $=$ base $\times \frac{1}{2}$ height or height $\times \frac{1}{2}$ base.

Area of rectilinear surface: divide into triangles, and take the sum of their respective areas.

Circle $= \pi \times (\text{radius})^2$. $\left(\pi = \frac{\text{C}^{\text{e}}}{\text{D}^{\text{m}}} = \frac{22}{7} = 3.1416\right)$.

or $= \frac{\pi}{4} (= 0.7854) \times (\text{diameter})$.

Circumference $= \pi \times$ diameter $= 2\pi \times$ radius.

$$\text{Diameter} = \frac{\text{circumference}}{\pi}.$$

$$\text{Segment of circle} = \tfrac{2}{3} \times \text{chord} \times \text{height} + \frac{\text{cube of height}}{2 \times \text{chord}}.$$

$$\text{Ellipse} = \frac{\pi \times \text{long diam.} \times \text{short diam.}}{4}$$ (long diam. = major axis; short " = minor ")

Cubical measurement of:

Cube or solid rectangle = length × breadth × height.
Solid triangle = sectional area of triangle × height.
Cone or pyramid = area of base × $\frac{1}{3}$ height.
Dome = " × $\frac{2}{3}$ "
Cylinder = " × "

$$\text{Sphere} = \frac{4\pi(\text{radius})^2}{3}.$$

$$\text{or} = \frac{\pi}{6} \times (\text{diameter})^3$$
$$= 0.5236 \times (\text{diameter})^3$$

Trapezium.

Trapezium:
$\frac{\text{Lengths of parallel sides}}{2} \times$ vertical distance between them.
Parallelogram: length of one side × vertical distance between the parallel sides.

Parallelogram.
FIG. 17.

To Estimate the Cubic Area from the Floor-plan of a Room with Dimensions: uniform height = 12.5 feet. FD = 2 feet.
The furniture, &c., occupies 118 cubic feet.
How many adults can occupy it as a sitting-room during the day?

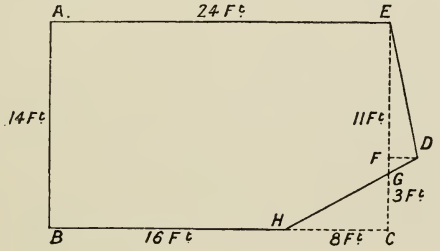

FIG. 17*a*.—Area of Room.

Superficial area of ABCE = 24 × 14 sq. ft.
Cubic " " " = 24 × 14 × 12.5 = 4200 cubic feet.
Adding cubic space of EGD:

Superficial area = $\frac{11}{2} \times 2 = 11$ sq. ft.
Cubic " 11 × 12.5 = 137·5 "
4337·5 "

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Deducting cubic space of HCG :

Superficial area = 4 × 3 = 12 sq. ft.		
Cubic ,, 12 × 12.5	= 150.0	cubic feet.
	4187.5	,,
Deducting cubic space for furniture, &c.	118.0	,,
	4069.5	,,

For a cubic space of 1000 cub. ft. per head : suitable for 4 persons
,, ,, ,, 300 ,, ,, ,, ,, 13 ,,

Cubic and Superficial Spaces in Hospitals.

The following data may be taken as a fair average :
Maximum number of cases in a ward = 30.

Hospitals for Infectious Diseases.

Cubic air space = 2000 cubic feet ($=\frac{1}{3}$ more than in General Hospitals).

Superficial floor area = 144 square feet ($=\frac{1}{6}$ more than in General Hospitals).

Wall-space = 12 linear feet ($=\frac{1}{2}$ more than in General Hospitals).

General Hospitals.

Each to have cubic air space = 1500 cubic feet.

Superficial floor-area = 125 square feet = $\frac{1}{12}$ cubic space.

Wall-space = 8 linear feet.

Open-window area = 20 square feet = 1 square foot per 75 cubic feet of air space, about $\frac{1}{6}$ floor-area.

Air supply per patient per hour = 4000 cubic feet.

Each window to be 3 feet above the floor and 6 inches short of the ceiling.

Width of ward = 25 feet.

Height ,, = 15 ,,

Length depends on the number of beds, the cubic space and floor-area. If the above data are carried out for 30 patients, the length must be : $\frac{45000}{25 \times 15} = 120$ feet.

With an air space of 1500 cubic feet and a supply of 4000

cubic feet of fresh air per case per hour the air must be renewed $\frac{4000}{1500} = 2.\dot{6}$ ("recurring decimal") times per hour.

If the ward is to be 100 feet long—let x be the number of patients it can contain, the above conditions being fulfilled:

$$\frac{1500\ x}{25 \times 15} = 100. \quad x = 25 \text{ patients.}$$

Beds.—Length of each, 6 feet. Width, 3 feet. Average cubic space occupied by bed and bedding, 10 cubic feet; by each patient (adult), 3 cubic feet.

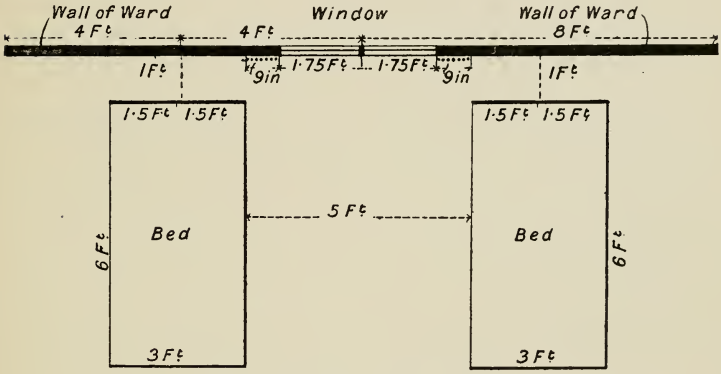

Fig. 18.—Spacing of Beds in Ward.

Each bed is to be at least 5 feet clear of the next one, and is best placed between two windows.

An equal number of beds is placed on each side of the ward. If there are 15 a side there must be 16 windows, or 32 in all, as the first and last beds on each side have one end-window (top and bottom of ward) to themselves.

Length of ward = 120 feet; 15 beds down each side; length of wall for each bed = 8 feet, or 4 feet from the middle line of each bed.

Width of bed = 3 feet. Total free space per bed = 8 − 3 = 5 feet, or 2.5 feet on each side (4 − 1.5 = 2.5 feet). This leaves a clear space of 5 feet between adjacent beds.

If the ward is 15 feet high and each window is 3 feet above the floor and 6 inches short of the ceiling, its total length = 15 − 3.5 feet = 11.5 feet. As the upper *half* of the window usually opens, its width to obtain an open space of 20 square feet must

be $\frac{11.5}{2} \times$ width $= 20$ square feet; width $= \frac{20}{5.75} = 3.5$ feet.

A window being placed centrally between two beds (*i.e.*, in the centre of the intermediate space of 5 feet) $\frac{3.5}{2}$ or 1.75 feet of this wall-space is occupied by the window, leaving a distance of $2.5 - 1.75 = 0.75$ feet or 9 inches between the side of the bed and that of the adjacent window, measured along the wall. As the head of the bed is placed about a foot off the wall this distance is only relative to the surface of the wall.

Distance between centres of two windows = 8 feet.

Wall-space between adjacent sides of two windows = 4.5 feet.

EXAMPLE.—A ward for general cases is to contain 8 beds. Calculate the dimensions and window-space, &c.

Total cubic space $= 1500 \times 8$ . . = 12,000 cubic feet.

„ floor „ $= 125 \times 8$ . . = 1000 square „

Length $\times 25 \times 15 = 12{,}000$ ∴ length . = 32 feet.

Wall-space $= \frac{32}{4}$ . . . . = 8 feet per bed.

Space between beds $= 8 - 3$ . . . = 5 feet (2.5 feet on the sides of each bed).

Total window area $= \frac{12000}{75}$ . . . = 160 square feet (about $\frac{1}{6}$ floor-space). 80 square feet on each side of the ward.

One bed between two windows . . = 5 windows on each side of the ward.

Area of each window $= \frac{80}{5}$ . . . = 16 square feet.

Total length of window . . . = 11.5 feet.

Half the length usually opens, therefore width of window $\frac{16}{5.75}$ . . . = 2.78 feet.

Distance between edge of bed and sides of adjacent windows (measured along wall) $= 2.5 - \frac{2.78}{2}$ . . . . = 1.1 foot.

If all the 10 windows were open at the upper half, and formed the only means of ventilation, total inlet-area = 160 square feet, and total air-supply . . = 32,000 cubic feet per hour.

Velocity of air current $= \frac{32{,}000}{160}$ . . $\left\{ \begin{array}{l} = 200 \text{ linear ft. per hr.} \\ 0.06 \quad \text{,,} \quad \text{,,} \quad \text{,,} \text{ sec.} \end{array} \right.$

If the ward had a residual amount of fresh air equal to its cubic capacity (12,000 cubic feet) before it was occupied by the 8 patients, the amount of fresh air required to be supplied through the 10 windows would be 32,000 − 12,000 = 20,000 cubic feet, and the velocity of the air-current *during the first hour* of occupation would be $\frac{20{,}000}{160}$ $\left\{ \begin{array}{l} = 125 \text{ linear ft. per hr.} \\ 0.03 \quad \text{,,} \quad \text{,,} \quad \text{,,} \text{ sec.} \end{array} \right.$

Estimation of CO_2 in Air—Pettenkofer's Method.

I. Baryta water. 4.5 grammes Ba2(HO) per litre.*
Oxalic acid. Standard solution: 1 c.c. = 0.25 c.c. CO_2.

Method.—$C_2H_2O_4 + 2H_2O = 126$ grammes. $CO_2 = 44$ grammes. One molecule of acid combines with as much barium hydrate as one molecule of CO_2. Therefore 126 of oxalic acid correspond to 44 CO_2.

1 litre CO_2 at N.T.P. $= \frac{44}{2} \times 0.08936$ = 1.965 grammes.

$\frac{1}{4}$,, ,, ,, ... = 0.491 gramme.

∴ 44 : 126 :: 0.491 : x. . . . $x = 1.41$ grammes.

∴ 1.41 grammes of oxalic acid dissolved in 1 litre of water are equivalent to 0.25 c.c. CO_2.

The same result may be obtained by using Avogadro's law:

44 grammes CO_2 at N.T.P. . . = 22.32 litres.
∴ 126 ,, oxalic acid at N.T.P. . = 22.32 ,,

And $\frac{126}{22.32} = 5.64$ grammes oxalic acid = 1 litre of CO_2.

∴ 5.64 grammes oxalic acid dissolved in 1 litre of water = 1 litre of CO_2; and 1 c.c. of this solution = 1 c.c. of CO_2.

A solution containing $\frac{5.64}{4} = 1.41$ grammes oxalic acid per litre, 1 c.c. = 0.25 c.c. of CO_2.

II. Lime water. Clear solution (saturated).
Oxalic acid. Standard solution, 1 c.c. = 1 mgr. CaO. CaO = 56. $C_2H_2O_4 + 2H_2O = 126$. One molecule of acid combines with as much CaO as a molecule of CO_2.

56 : 1 : : 126 : x. $x = 2.25$ grammes.

* Or: Ba2(HO) 28 gms. $BaCl_2$ (10 % sol^n) 5 c.c. Water 4 litres.

2.25 grammes of oxalic acid per litre: 1 c.c. = 1 mgr. CaO.

$$\underset{(56)}{CaO} + \underset{(44)}{CO_2} = \underset{(100)}{CaCO_3}. \quad 1 \text{ mgr. } CaO = \frac{44}{56} \text{ mgr. } CO_2.$$

1 litre of CO_2 (or 1000 c.c.) $= \frac{44}{2} \times 0.0896 = 1.97$ grammes $= 1970$ mgrs.

$$1970 : \frac{44}{56} :: 1000 : x. \quad x = 0.4 \text{ c.c. } CO_2.$$

∴ 1 c.c. oxalic acid solution = 1 mgr. CaO = 0.4 cc. CO_2 (2.25 grammes per litre).

Example.—(1) Total air-capacity of dry jar = 4320 c.c.
100 c.c. pure baryta solution added (jar shaken for half an hour*).

25 c.c. pure baryta solution . = 42.8 c.c. oxalic acid solution.
25 c.c. baryta solution + CO_2 of air in jar . . . . . = 39.6 c.c. „ „ „

∴ 25 c.c. baryta solution + CO_2 of air in jar . . . . . = 3.2 c.c. „ „ „ representing CO_2 absorbed.

1 c.c. oxalic acid solution . . = 0.25 c.c. CO_2 (standard).

∴ $3.2 \times 0.25 = 0.8$ c.c. CO_2 in 25 c.c. baryta solution taken from jar.

$0.8 \times 4 = 3.2$ c.c. CO_2 in 100 c.c. baryta solution added to jar.

(As this amount is identical with the 3.2 c.c. obtained by subtraction above, the former result can be taken at once as the amount of CO_2 absorbed by 100 c.c. of baryta solution.)

Actual volume of air tested = 4320 − 100 = 4220 c.c.

Percentage of CO_2 present : 4220 : 100 :: 3.2 : x. $x = 0.076$ per cent. of CO_2 or 7.6 volumes CO_2 per 10,000 volumes of air "at *current temperature and pressure*" (1 cubic metre = 1000 litres).

If temperature = 58.6° F., and pressure = 29.264 inches, it is unnecessary to alter these to C° and mm.:

To correct for normal temperature and pressure (32° F. and 30 inches):

$$V_n = \frac{4220 \times (459 + 32)}{(459 + 58.6)} \times \frac{29.264}{30} = 3904.9 \text{ c.c. of air at N.T.P.}$$

3904.9 : 100 :: 3.2 : x. $x = 0.08$ per cent. of CO_2, or 8 volumes CO_2 per 10,000 volumes of air.

As the "correction" for N.T.P. is trifling, it is, as a rule,

* Clowes and Coleman shake up for half an hour and titrate the whole of the lime-water in the bottle itself (*Quantitative Analysis*).

only made at altitudes above sea-level where the difference of pressure is considerable.

EXAMPLE.—(2) Total capacity of air-jar = 4640 c.c.

100 c.c. of lime-water added (jar shaken for three-quarters of an hour).

25 c.c. pure lime-water . . = 39.6 c.c. oxalic acid solution

25 c.c. of lime-water from jar . = 34.8 c.c. „ „ „

∴ 25 c.c. of lime-water from jar { = 4.8 c.c. „ „ „ corresponding to CO_2 absorbed

Oxalic acid solution : 1 c.c. . = 0.4 c.c. CO_2 (as above).

∴ 4.8 × 0.4 . . . . { = 1.92 c.c. CO_2 in 25 c.c. of lime-water from jar.

1.92 × 4 . . . . { = 7.68 c.c. CO_2 in 100 c.c. of lime-water added to jar.

Air in jar = 4640 − 100 . . = 4540 c.c.

∴ 4540 : 100 : : 7.68 : x. $x = 0.169$ per cent. of CO_2 in air, or 16.9 volumes of CO_2 in 10,000 volumes of air, "at current temperature and pressure."

Supposing temperature and pressure are to be expressed in C.° and mm., and are read originally as 46.5° F. and 30.46 inches. These correspond to 7.4° C. and 771.65 mm.

To correct 4540 c.c. of air to N.T.P. (0° C. and 760 mm.),

$$V_n = \frac{4540 \times (273+0)}{(273+7.4)} \times \frac{771.65}{760} = 4506.7 \text{ c.c. of air at N.T.P.}$$

4506.7 : 100 : : 7.68 : x. $x = 0.17$ per cent. of CO_2 in air, or 17 volumes of CO_2 per 10,000 volumes of air.

Estimation of CO_2 in Air by aspiration through Pettenkofer's Absorption-tubes.

Baryta solution, strength as before (p. 71), or it may be twice as strong.

First tube may contain 150 c.c. or 100 c.c. of solution, and second tube 100 c.c. If the solution is sufficiently turbid after 1 to 4 litres have passed, the aspiration may be stopped and the estimation of CO_2 made. As a rule, in the open air 10 litres are passed through at the rate of 1 litre every quarter of an hour or 10 litres in two and a half hours. The mean temperature and pressure must be observed during the process, and if the

fluctuations are not great, may be taken at "half-time" as an approximation.

Example.

Pure baryta solution: 25 c.c. = 42.6 c.c. oxalic acid solution. 10 litres air aspirated.

First tube (containing 100 c.c. pure baryta solution):

25 c.c. = 39.7 oxalic acid solution.

42.6 − 39.7 = 2.9 c.c. equal to CO_2 absorbed by 100 c.c. baryta soln.

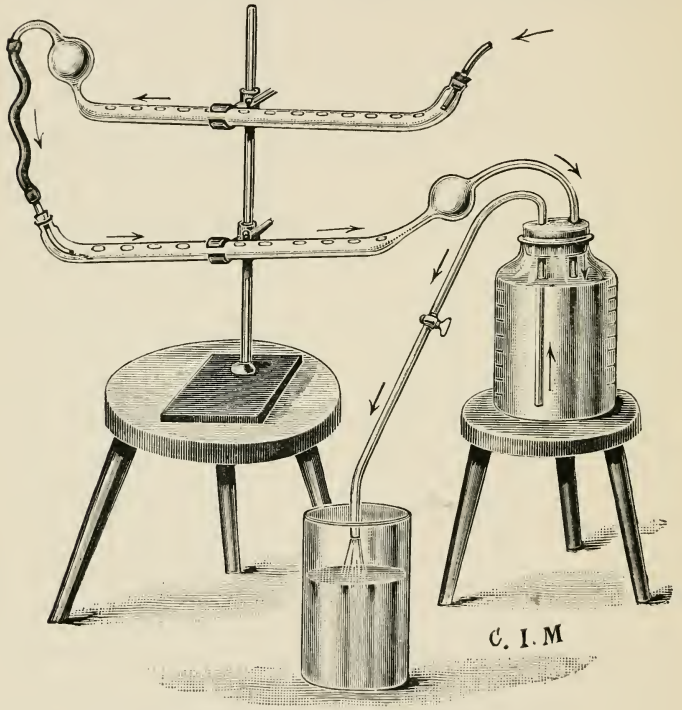

Fig. 19.—Estimation of CO_2 by Pettenkofer's Tubes.

Second tube (containing 100 c.c. pure baryta solution)

25 c.c. = 42.2 c.c. oxalic acid solution.

42.6 (pure baryta solution) − 42.2 = 0.4 c.c.:

∴ 2.9 + 0.4 = 3.3 c.c. in 10 litres of air.

Supposing 10 litres of air (10,000 c.c.) *corrected for N.T.P.* = 9850 c.c.

$\therefore$ 9850 : 10,000 : : 3·3 : x. $x = 3{\cdot}35$ volumes of CO_2 per 10,000 or 0.035 CO_2 per cent.

(This method is more accurate than the first; but though 10 litres of water are run off—or 1 litre made to aspirate 10 times by reversing the bottles—some of the air in the apparatus diffuses out.)

CHAPTER V.

WATER.

WATER is taken as the standard for determining the unit of heat, the specific heat and latent heat of a body, and also as the standard for ascertaining the relative density or specific gravity of solids and liquids, as already indicated.

The unit of heat is the amount of heat required to raise unit mass of water one degree in temperature. It varies with the unit of mass and scale of temperature adopted:

Centigrade Scale.—A *kilo*gramme of water at 0° C. is the unit of mass, and the amount of heat required to raise its temperature from 0° to 1° C. is the unit of heat known as the "*Calorie*." The small *calorie* is the heat that will raise one *gramme* to the same extent.

Fahrenheit Scale.—The amount of heat necessary to raise the temperature of a pound of water 1° F. either from 32° F. to 33° F. or from 60° F. to 61° F.—the latter temperature being the usual one—is the British unit of heat.

The specific heat of a body is the ratio of the amount of heat taken in by the body when its temperature increases one degree to the amount of heat taken in by an equal weight of ice-cold water for a similar rise of temperature.

By "Dulong and Petit's law," the specific heat of an element varies inversely as its atomic weight.

In the Centigrade system the temperature of the water is taken at 4° C.—*i.e.*, at maximum density. In the Fahrenheit scale it is estimated at 60° F.

The specific heat of a substance when mixed with another can be ascertained by the following formula:

Let S.H.$_1$ = Specific Heat, W_1 = Weight, and t_1 = temperature of the one substance.

Let S.H.$_2$ = Specific Heat, W_2 = Weight, and t_2 = temperature of the other substance.

Let T = common temperature of both substances after mixing.

$$\frac{\text{S.H.}_1}{\text{S.H.}_2} = \frac{W_2 \times (T - t_2)}{W_1 \times (t_1 - T)}.$$

If S.H.$_2$ = specific heat of water, it is equal to 1.

$$\therefore \text{S.H.}_1 = \frac{W_2 \times (T - t_2)}{W_1 \times (t_1 - T)}.$$

Example.—A kilogramme of iron at a temperature of 100° C. is placed in a kilogramme of water at 4° C. On cooling, the common temperature is found to be 13.8° C.

The specific heat of iron is found as follows:

$$\frac{1 \times (13.8 - 4)}{1 \times (100 - 13.8)} = \frac{9.8}{86.2} = 0.114.$$

Example.—A kilogramme of ice is mixed with two kilogrammes of boiling water. Find the temperature of the water when the ice has melted. The specific heat of ice is 0.505.

$$\frac{2(T - 100)}{1(0 - T)} = 0.505. \quad 2T - 200 = -0.505T.$$
$$2.505T = 200T = 79.8° \text{ C.}$$

Latent heat is the heat absorbed by a body in changing from a solid to a liquid ("latent heat of fusion"), or from a liquid to a gaseous state ("latent heat of evaporisation"). It is a transformation of energy in the form of heat into another form of molecular energy. The latent heat of water is 80 heat-units of the Centigrade scale, and 143 heat-units of the Fahrenheit system.

The latent heat of steam is 536 kilogramme-units C., and 966 pound-units F.

Calculations of Water-Supply.

Data required: Depth of water.
Area of the receiving-surface.
Loss by evaporation, &c.

Rain Water.—The depth of rainfall is calculated by the rain-gauge (*vide* Meteorology) and by recorded observations extending over many years.

Hawksley's Formula for the Estimation of Rainfall:

1. Ascertain the average rainfall for 20 years.
2. Amount of rainfall in the wettest year = average rainfall + $\frac{1}{3}$.
3. „ „ driest „ = „ „ − $\frac{1}{3}$.

Or amount of rainfall in the driest year = average rainfall in 3 driest years.

Symons' Formula (for the British Isles):

Let the average rainfall = 1.

Rainfall in the wettest year = $1 + \frac{1}{2} = 1.5$ (half above the average).

" " driest " = $1 - \frac{1}{3} = \frac{2}{3}$ or 0.7 (one-third below the average).

" " " of 3 consecutive years = $1 - \frac{1}{5} = 0.8$ (one-fifth below the average).

EXAMPLE.—Supposing 37.3 inches = the mean rainfall of the United Kingdom:

By Hawksley's formula: Wettest year = 37.3 + 12.63 = 49.93 ins.
Driest " = 37.3 − 12.6 = 24.7 "
By Symons' " Wettest " = 37.3 + 18.65 = 55.95 "
Driest " = 37.3 − 12.6 = 24.7 "
Driest of three consecutive years = 37.3 − 7.46 = 29.84 "

1 inch of rainfall over 1 square yard of surface (1296 square inches) = 1296 cubic inches. 277.27 cubic inches = 1 gallon.

∴ 1 inch of rainfall over 1 square yard of surface (1296 square inches) = $\frac{1296}{277.27}$ = 4.67 gallons.

1 inch of rainfall on 1 acre = 4.67 × 4840 = 226028 gallons.

1 gallon of water at 62° F. = 10 lbs.

1 inch of rainfall over surface of 1 acre (at 62° F.) = $\frac{22602.8 \times 10}{2240}$

= 100.9 or 101 tons nearly.

Area of Receiving-surface.—The watershed may be estimated from the contour-lines of an Ordnance Map. Where contiguous lines are far apart the slope is small, and where they are close the land is steep and the "head" of water great. The point at which one contour-line crosses another is a "col" or "saddle-back"—the upper level descending to the lower. All water-courses, marking lines of greatest incline, cut the contour-lines at right angles.

If the rain-water sinks into a porous stratum which is *not* overlying an impervious layer, the effective receiving-surface cannot be determined by the watershed of the porous layer, but only by that bounding an underlying *impervious* stratum, which may be ascertained from a Geological Map of the district.

$$\frac{\text{Area of receiving-surface in square feet} \times \text{rainfall in inches}}{12} =$$

cubic feet of water per annum.

0.16 cb. ft. = 1 gallon. ∴ 1 cb. ft. = $\frac{1}{0.16}$ gallon = 6.25 gallons.

The usual estimate is 6.23 gallons.

Temperature of the air, the nature of the receiving-surface, growing vegetation, &c., cause a loss of water by evaporation, leakage and absorption, which is to be deducted from the above. These conditions vary indefinitely. As a rough estimate $\frac{1}{4}$ may be deducted from the amount, which is equivalent to multiplying the result by 0.75. A more accurate result is obtained by estimating at the same time the rainfall and the actual discharge of streams supplied by the area.

If the surface is a sloping roof, only the horizontal area it covers is to be estimated as a "receiving-surface."

EXAMPLE.—Area of receiving-surface = 2000 square feet.

Mean annual rainfall = 26.7 inches.

Volume of water available per annum, after deducting $\frac{1}{4}$ for evaporation $= \frac{2000 \times 144 \times 26.7}{1728} \times 0.75.$

$= \frac{2000 \times 26.7}{12} \times 0.75 = 3337.5$ cubic feet per annum.

$= 3337.5 \times 6.25 = 20859.375$ gallons, or 57 gallons per diem.

Hawksley's Formula for Storage in the impounding reservoir.

Number of days' storage = D.

Mean annual rainfall in inches for three consecutive dry years = F. $D = \frac{1000}{\sqrt{F.}}$.

EXAMPLE.—Mean annual rainfall = 49.61 inches.

Taking Symons' formula and deducting $\frac{1}{5}$ (*i.e.*, multiplying the mean annual rainfall by 0.8):

Mean annual rainfall of the driest of three consecutive years = $49.61 \times 0.8 = 39.69$ inches.

Days' storage $= \frac{1000}{\sqrt{39.69}} = \frac{1000}{6.3} = 158.73$ days.

Dr. Pole's Formula for the Area of the Collecting-surface:

Mean annual rainfall in inches = R.

Daily supply in gallons = G.

Area of collecting-surface in acres = A.

Loss by evaporation in *inches* = E.

$$G = 62\ A\ (R - E).$$

In a rainy place: $150\ G = 62\ A\ (R - E)$.

„ dry „ : $200\ G =$ „ „ „

EXAMPLE.—10,000 gallons are required as a daily supply. Estimating a loss by evaporation of $\frac{1}{5}$ R in all cases.

(1) Where R = 25 inches.

$10{,}000 = 62\ A\ (25 - 5)$. $62\ A = \frac{10{,}000}{20}$. $A = 8$ acres.

(2) In a wet place with a rainfall of 50 inches:

$10{,}000 \times 150 = 62\ A\ (50 - 10)$.

$$A = \frac{10{,}000 \times 150}{62 \times 40} = 605 \text{ acres.}$$

(3) In a dry locality where the rainfall is 15 inches:

$10{,}000 \times 200 = 62\ A\ (15 - 3)$.

$$A = \frac{10{,}000 \times 200}{62 \times 12} = 2688 \text{ acres.}$$

Water-Supply of a Stream.—Current-meters are used to indicate the rate of flow or the supply in gallons.

The stream is also dammed up and the water conveyed along a channel of known dimensions, which may be a trough—*i.e.*, length, width and depth and the velocity of the current are estimated along the length of the channel by using a float as indicator.

Outflow = velocity × width × depth.

(1) Discharge through a sluice: Area of the sluice = width × height.

"Head of Water":

(*a*) sluice above the lower level, = height of the upper level of the water above the centre of the opening of the sluice.

(*b*) Sluice entirely below the lower level, = difference of level of the water above and below the dam.

Discharge in cubic feet = area × $5\sqrt{\text{head of water}}$. (Poncelet and Lesbro's formula.)

Example.—The sluice has a length of 10 feet and a height of 2 feet, the height of the upper level of water above the centre is 6.76 feet.

Discharge = $10 \times 2 \times 5\sqrt{6.76}$.

$= 100 \times 2.6 = 260$ cubic feet.

(2) Di-charge over weir: theoretically it is equal to that of a body falling freely through the distance of surface-level above and below the weir: $v^2 = 2gh$, or $v = 8\sqrt{H}$ (as in Montgolfier's formula). This is the velocity of the *lowest* stratum of water: the average velocity is $\frac{2}{3}$ of $8\sqrt{H}$.

Blackwell's Formula for Discharge over a Weir:

Q = cubic feet per minute passing over weir.

w = width of weir in feet.

d = depth in inches over weir.

4.5 = "factor" (varying from 3.5, depth = 1 inch; to 4.4, depth = 9 inches).

$Q = 4.5 \times w \sqrt{d^3}$.

EXAMPLE.—Width of weir = 9 feet.
Depth ,, ,, = 4 inches.

$Q = 4.5 \times 9 \times \sqrt{4^3} = 4.5 \times 9 \times 8 = 324$ cubic feet per minute.

Yield of a Stream.

Ascertain the mean depth by repeated soundings along as uniform a channel as possible, noting the length and breadth, and the surface velocity of the current by a float.

The mean velocity is estimated as $\frac{4}{5}$ or 0.8 (by some as $\frac{2}{3}$) the surface velocity.

EXAMPLE.—Width of stream = 16.5 feet; mean depth = 4 feet.

Velocity of surface current = 45 feet in 70 seconds = 38.6 feet per minute.

Mean velocity = 38.6×0.8.

Sectional area = 16.5×4 square feet.

Outflow = $16.5 \times 4 \times 38.6 \times 0.8 = 2038.08$ cubic feet per minute.

$2038.08 \times 6.25 = 12{,}738$ gallons per minute.

The Hydraulic Ram is employed to raise water from a stream to a maximum height of about 150 feet. For any height above this the proportion of water wasted exceeds the amount supplied. Height to which water can be raised = 25 × height of fall ("head"). A fall below 12 inches is ineffective, and one above 6 feet causes too great a strain on the apparatus.

If height of fall = 6 feet, $25 \times 6 = 150$ feet or maximum "lift." From 50 to 80 per cent. of the available power can be utilised. The waste water is troublesome to dispose of.

PROBLEM.—"Assuming that in a chalk formation the quantity of retained water is 16 per cent. of the volume of the chalk, and that the curve of saturation is a straight line, find the number of gallons of water contained in a hill $1\frac{1}{2}$ miles wide (*i.e.*, measured at right angles to the line of greatest slope) and in which the highest point of the curve of saturation is 51 feet vertically above the lowest and a mile from it horizontally." (*Cambridge University.*)

Area of *triangular surface* A B C

= base × $\frac{1}{2}$ height.

$= 5280 \times \frac{51}{2}$ feet.

Area of *solid triangle* A B C D E A
= area of A B C × A E
$= 5280 \times \frac{51}{2} \times (1\frac{1}{2} \times 5280)$ cubic feet.
= 1,066,348,800 cubic feet in which water = 16 per cent.
100 : 16 :: 1,066,348,800 : x.
x = 666,468 cubic feet × 6.25
= 4,165,425 gallons.
(1 cubic foot of water = 6.25 gallons.)

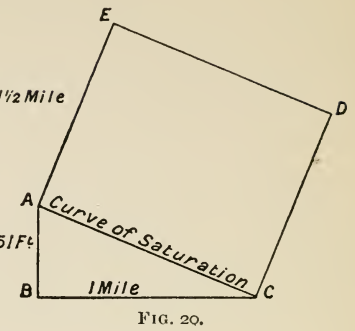

FIG. 20.

The Suction-pump.—Atmospheric pressure on the external surface of water causes it to rise into the pump-barrel, when the ascent of the piston produces a vacuum.

Maximum height of mercurial column supported by atmospheric pressure = 30 inches or 2.5 feet.

Mercury is 13.6 times heavier than water.

∴ Maximum height of water-column supported by atmospheric pressure = 2.5 × 13.6 = 34 feet.

The piston when raised to its highest point must, theoretically, not exceed a height of 34 feet from the surface of water outside.

EXAMPLE.—Length of piston-stroke = 6 inches.

Height of suction-valve (at bottom of pump-barrel) above water = 20 feet.

"Untraversed space" between lowest point of descent of piston and the suction-valve = 1.5 inches.

Air-pressure within barrel when piston at highest point = $\frac{1.5}{6+1.5}$ of atmospheric pressure.

Atmospheric pressure = pressure of 34 feet of water.

∴ Column of water supported by this pressure = $34 \times \frac{1.5}{7.5}$ = 6 8 feet.

∴ Maximum height to which water can be raised by pump = 34 − 6.8 = 27.2 feet.

Practically, owing to loss of energy from friction and the presence of "untraversed space" at the bottom of the barrel, the height cannot be more than 25 feet above the surface of water.

Velocity of Efflux of Liquids.—"Torricelli's Theorem." The velocity is equal to that acquired by a body falling freely in

air from a state of rest at the upper surface of the fluid to the centre of the orifice. The velocity is greater as the surface of fluid is above the centre of the orifice, *i.e.*, it increases with the "head" of the liquid, or its height above the opening.

$\therefore v^2 = 2gh$ (*vide* p. 58). $v = \sqrt{2gh}$. $(g = 32.)$

EXAMPLE.—Let "head" at A (Fig. 21) = 1 inch, and velocity = 3 inches per second.

" " B = 4 inches.

velocity of efflux at B = velocity at A $\times \sqrt{4}$

$= 3 \times 2 = 6$ inches per second.

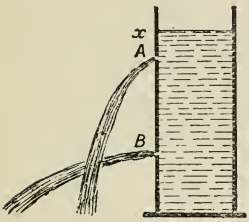

FIG. 21.—Efflux of Liquids.

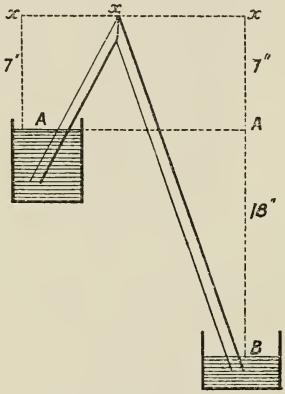

FIG. 22.—Syphon.

This is the velocity at the "vena contracta" of the jet, *i.e.*, the point in the section of the jet where the flow is in parallel lines.

The Syphon.—Let A = level of liquid in upper vessel.

B = " " lower "

x = highest point of syphon.

Vertical height of x above A = 7 inches.

" " " B = 25 "

" " A " " = 25 − 7 = 18 inches.

Atmospheric pressure on both surfaces = 30 inches of mercury.

Pressure on the A-side of $x = 30 - 7 = 23$ inches.

" " B-side " $= 30 - 25 = 5$ "

$\therefore$ Difference of pressure at $x = 23 - 5 = 18$ = due to difference of level of surfaces A and B, and not to length of "legs."

Theoretically, the highest point (x Fig. 22) of a syphon intended for water must not be more than 34 feet above the upper surface A, at sea-level, as the air-pressure then is equal to

34 feet of water. Practically—owing to loss of energy from friction—it should not exceed about 33 feet.

The Hydraulic or Bramah Press is a practical application of "Pascal's law": "Pressure exerted anywhere upon a mass of liquid is transmitted equally in all directions in a closed vessel,

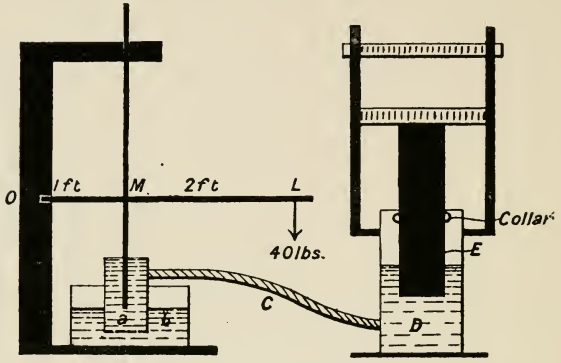

FIG. 23.—Bramah Press.

and acts with the same force on all equal surfaces and at right angles to them."

a = force-pump (Fig. 23).

b = water reservoir.

OL = lever. OM = junction of lever and pump "plunger."

C = connecting-pipe.

D = cistern of press. E = ram's "plunger" with "cupped leather collar" to prevent escape of water.

If pressure at L = 40 lbs.

„ sectional area of E = 100 times that of the piston in a.

„ OL = 3 × OM.

Upward pressure of plunger = 40 × 3 × 100 = 12,000 lbs.

CHEMICAL CALCULATIONS.

Total Solids.

(*a*) 100 c.c. of sample water evaporated.

Weight of platinum capsule + solids after drying and desiccation . . . . = 43·317 grammes.

Weight of platinum capsule previously incinerated, cooled and "desiccated" . = 43·285 „

Total solids in 100 c.c. of sample 0.032 „

= 0.032 gramme in 100 grammes of sample (taking 1 c.c. = 1 gramme

= 32 parts per 100,000 (32 × 0.7 = 22.4 grains per gallon).

(*b*) 70 c.c. of water are evaporated.

Total weight of capsule and solids = 34 42 grammes.

„ „ „ alone = 34·33 „

Weight of total solids in 70 c c. of water = 0.09 „

or 9 milligrammes ∴ = 9 grains per gallon of total solids.

After ignition, cooling, &c.

Weight of capsule and residue = 34.346 grammes.

34·346 − 34.33 = 0.016 grammes or 1.6 milligrammes volatile solids in 70 c.c. of water, = 1.6 grains volatile solids per gallon.

Estimation of Chlorine.

A colour-reaction with the formation of permanent orange-red chromate of silver indicating the amount of chlorine used up.

Standard solution of silver nitrate 1 c.c. = 1 mgr. of Cl.

$$\underset{(170)}{AgNO_3} + \underset{(58.5)}{NaCl} = \underset{(143.5)}{AgCl} + \underset{(85)}{NaNO_3}. \quad Cl = 35.5.$$

35·5 mgr. Cl : 1 mgr. Cl : : 170 mgrs. $AgNO_3$: x mgrs. $AgNO_3$ (monovalent). $x = \frac{170}{35.5} = 4.788$ mgrs. $AgNO_3$. *i.e.*, 4.788 mgr. $AgNO_3$ in 1 c.c. of water = 1 mgr. Cl. Therefore 4.788 grammes of $AgNO_3$ dissolved in 1 litre of water form a solution of which 1 c.c. = 1 mgr. of chlorine. The bottle containing it may be labelled "1 c.c. = 1 mgr. Cl." or "4.788 grammes $AgNO_3$ per litre." If labelled 14.384 grammes per litre and a solution of the above strength is required: By the equation it is found that 4.788 grains per litre = 1 mgr. Cl. in 1 c.c. ∴ 4.788 : 16.758 : : 1 : x. $x = 3.5$ or 1 c.c. contains 3.5 mgr. Cl—*i.e.*, the solution is three and a half times too strong. It is diluted down to the required standard by taking 10 c.c. and adding 25 c.c. of distilled water, thus making it up to 35 c.c. 1 c.c. of this will contain 1 mgr. of chlorine.

If using a deci-normal solution of nitrate of silver :

170 grammes $AgNO_3$ per litre = N. $\therefore \frac{N}{10} = 17$ grammes per litre = 3.55 grammes Cl. 1 c.c. of solution = 0.00355 grammes Cl or 3.55 mgrs. Use from 100 (*Lehmann*) to 250 c.c. of water for testing, otherwise the colour develops too quickly.

Examples.

(*a*) 100 c.c. of water took 3.5 c.c. standard solution of silver nitrate (strength 1 c.c. = 1 mgr. Cl.) to give permanent orange,

= 3.5 mgr. Cl. in 100 c.c. of water, or 3.5 parts per 100,000. ($3.5 \times 0.7 = 2.45$ grains per gallon.)

(*b*) 70 c.c. water taken. Required 11.7 c.c. standard (1 c.c. = 1 mgr. Cl.) = 11.7 mgr. Cl. or 11.7 grains per gallon, or 16.7 parts per 100,000 of chlorine.

(*c*) 250 c.c. of water required 2.8 c.c. $\frac{N}{10} AgNO_3$ solution.

(1 c.c. = 3.55 mgrs. Cl.)

$2.8 \times 3.55 = 9.94$ mgrs. Cl. in 250 c.c. water.

$9.94 \times 4 = 39.76$ mgrs. per litre.

= 3.976 centigrammes per litre or parts per 100,000.

(= 2.73 grains per gallon).

As 9.94 mgrs. in 250 c.c. = parts per 250,000, to obtain parts per 100,000 divide at once by 2.5 : $\frac{9.94}{2.5} = 3.976$ parts of chlorine per 100,000.

(N.B. The water, silver solution, and chromate of potassium solution ("Indicator") must not be acid, otherwise the orange reaction will not be permanent—the red chromate of silver gets dissolved.)

Chlorine in Terms of Sodium Chloride.

Cl = 35.5, NaCl = 58.5.

35.5 : 1 :: 58.5 : x. $x = 1.65$.

E.g., 3.976 parts per 100,000 of chlorine = $3.976 \times 1.65 = 6.38$ parts per 100,000 of NaCl.

Hardness.

Standard solutions calculated.

(A) Standard soap solution. Strength 1 c.c. = 1 mgr. $CaCO_3$.

Standard solution of pure calcium chloride for standardising the soap-solution :

$CaCl_2 = 111$. $CaCO_3 = 100$. 100 : 1 :: 111 : x.

$x = 1.11$ grammes $CaCl_2$.

1.11 grammes $CaCl_2$ per litre = 1.00 gramme $CaCO_3$ per litre.
1 c.c. = 1 mgr. $CaCO_3$.

Standard soap solution :

10 grammes Castile soap.
350 (or 700) c.c. methylated spirit.
650 (or 300) c.c. distilled water.

Strength : 1 c.c. = 1 mgr. $CaCO_3$.

(B) Standard soap solution. Strength 1 c.c. = 2.5 mgr. $CaCO_3$.

Standard solution of barium nitrate for standardising the soap-solution :

$Ba2NO_3 = 261$. $CaCO_3 = 100$. ∴ 0.261 gramme $Ba2NO_3$ per litre = 0.1 mgr. $CaCO_3$ per litre. 1 c.c. = 0.1 mgr. $CaCO_3$. 50 c.c. $Ba2NO_3$ solution = 5 mgr. $CaCO_3$.

Standard soap solution : 2 c.c. = 50 c.c. $Ba2NO_3$ solution.
∴ 2 c.c. = 5 mgr. $CaCO_3$. 1 c.c. = 2.5 mgr. $CaCO_3$.

Total Hardness.—(A) Standard soap solution : Strength—1 c.c. = 1 mgr. $CaCO_3$.

100 c.c. water = 13.5 c.c. standard soap solution to form permanent lather.

100 c.c. *distilled* water = 1 c.c. standard.

∴ 13.5 − 1 = 12.5 c.c.—*i.e.*, 12.5 mgr. $CaCO_3$ in 100 c.c. of water = 12.5 parts per 100,000 of total hardness. (12.5 × 0.7 = 8.75 grains $CaCO_3$) per gallon, corresponding to 8.75° of Clark's scale.

To express $CaCO_3$ in equivalent terms as CaO :

$CaCO_3 = 100$. $CaO = 56$. $100 : 1 :: 56 : x$. $x = 0.56$.

∴ 12.5 parts per 100,000 of $CaCO_3 = 12.5 \times 0.56 = 7$ parts per 100,000 of CaO (8.75 × 0.56 = 4.9 grains CaO per gallon).

Permanent Hardness—250 c.c. of water boiled down to about 150 c.c., cooled, filtered, and made up to 250 c.c. with boiled distilled water, 100 c.c. of clear liquid took 5.5 c.c. soap solution. 5.5 − 1 = 4.5 c.c. = 4.5 mgr. $CaCO_3$ in 100 c.c. or 4.5 parts $CaCO_3$ per 100,000 (3.15 grains per gallon).

Temporary Hardness.—12.5 − 4.5 = 8 parts per 100,000 ; or 4.9 − 3.15 = 0.75 grains per gallon.

Total Hardness.—70 c.c. water took about 29 c.c. soap solution (same strength).

To obtain a more accurate result : To 70 c.c. fresh sample-water 70 c.c. distilled water were added, and needed 29.5 c.c. standard soap solution to give a permanent lather.

If 70 c.c. distilled water take 1 c.c. soap solution for the extra 70 c.c. of water added, 2 c.c. must be deducted.

∴ 29.5 − 2 = 27.5 mgr. $CaCO_3$ in 70 c.c. of sample = 27.5 grains

$CaCO_3$ per gallon, of total hardness, corresponding to 27.5° of Clark's scale (39.3 parts per 100,000).

Permanent Hardness.—200 c.c. of water evaporated down to 100 c.c. filtered, &c., and made up to 200 c.c. as before.

70 c.c. = 16.8 c.c. soap solution. 16.8 − 1 = 15.8 mgr. $CaCO_3$ in 70 c.c. = 15.8 grains per gallon.

Temporary Hardness.—27.5 − 15.8 = 11.7 grains $CaCO_3$ per gallon.

(B) Standard soap solution. Strength: 1 c.c. = 2.5 mgr. $CaCO_3$ (Parkes and de Charmont).

Total Hardness. - 50 c.c. of water are taken.

0.2 c.c. standard solution produces a permanent lather in 50 c.c. of distilled water.

e.g., 50 c.c. sample-water = 3.8 c.c. soap solution.

3.8 − 0.2 = 3.6. 3.6 × 2.5 = 9 mgr. $CaCO_3$ in 50 c.c. of sample = 18 mgr. $CaCO_3$ in 100 c.c. or 18 parts $CaCO_3$ per 100,000. (12.6 grains per gallon = degrees in Clark's scale.)

(**Permanent and Temporary Hardness** are estimated in a similar way after the usual preliminaries.)

To reduce a soap solution of strength 1 c.c. = 2.5 mgr. $CaCO_3$ to a strength of 1 c.c. = 1 mgr. $CaCO_3$, take 10 c.c. of the former and "make up" with recently boiled distilled water to 25 c.c.

Estimation of Magnesia in Water after eliminating Calcium salts. *E.g.*, 70 c.c. of water free from calcium required 3.4 standard soap solution (strength 1 c.c. = 1 mgr. $CaCO_3$).

3.4 − 1 = 2.4 grains $CaCO_3$ per gallon (*vide supra*).

∴ Hardness from magnesium salts is equivalent to 2.4 grains $CaCO_3$ per gallon.

∴ 2.4 × 0.56 = 1.9 grains per gallon of $MgCO_3$.

Estimation of Free and Albuminoid Ammonia.

Wanklyn's Process. — Standard solution of ammonium chloride. Strength 1 c.c. = 0.01 mgr. NH_3 = 17. NH_4Cl = 53.5. 17 : 1 :: 53.5 : x. x = 3.15 grammes NH_3Cl or 1 part NH_3 = 3.15 parts NH_4Cl.

3.15 grammes NH_4Cl per litre = 1 gramme NH_3 per litre.

1 c.c. of this solution = 1 mgr. NH_3.

10 c.c. of this solution are made up to 1 litre with distilled water.

∴ 1 c.c. = 0.01 mgr. NH_3.

Example.—(1) *Free Ammonia.* 50 c.c. of water tested provisionally with 2 c.c. "Nessler" give a light tint, therefore 500 c.c. of the sample are taken for distillation.

1st 50 c.c. distillate = 2.6 c.c. standard NH_4Cl solution.
2nd „ „ = 1.2 „ „ „ „
3rd „ „ = 0.5 „ „ „ „
4th „ „ = 0.0 „ „ „ „
∴ 500 c.c. water = 4.3 „ „ „ „

0.01 (1 c.c. = 0.01 mgr. NH_3)

„ „ „ = 0.043 mgr. NH_3

2

1000 c.c. (1 litre) „ = 0.086 „ „

= 0.0086 centigramme NH_3 per litre or part per 100,000.
(0.0086 × 0.7 = 0.0602 grain per gallon.)

Albuminoid Ammonia.—After adding 50 c.c. alkaline permanganate to the remainder in the flask.

1st 50 c.c. distillate = 4.2 c.c. standard NH_4Cl solution.
2nd „ „ = 2.7 „ „ „ „
3rd „ „ = 1.3 „ „ „ „
4th „ „ = 0.2 „ „ „ „
500 c.c. sample = 8.4 „ „ „ „

0.01

„ „ = 0.084 mgr. NH_3

2

1000 c.c. (1 lit.) „ = 0.168 „ „

= 0.0168 centigramme NH_3 per litre or part per 100,000.
(0.01176 grain per gallon).

(2) 50 c.c. of water treated with 2 c.c. "Nessler" gave a darker colour.

250 c.c. of the sample were put in the distillation-flask.

Free Ammonia—
1st 50 c.c. distillate = 3.6 c.c. standard NH_4Cl solution.
2nd „ „ = 2.8 „ „ „ „
3rd „ „ = 1.4 „ „ „ „
4th „ „ = 0.3 „ „ „ „
250 c.c. sample = 8.1 „ „ „ „

2

500 „ „ = 16.2 „ „ „ „

0.01 (1 c.c. = 0.01 mgr. NH_3)

„ „ „ = 0.162 mgr. NH_3

2

1000 c.c. (1 lit.) „ = 0.324 „ „ or 0.0324 centigramme NH_3 per litre, or parts per 100,000.

0.0324 × 0.7 = 0.02268 grain per gallon.

Albuminoid Ammonia.—After adding 25 c.c. alkaline permanganate to the water remaining in the distillation-flask:

1st 50 c.c. distillate = 2.1 c.c. standard solution
2nd „ „ = 1.5 „ „ „
3rd „ „ = 0.8 „ „ „
4th „ „ = 0.0
250 c.c. sample = 4.4 „ „ „
2
500 „ „ = 8.8 „ „ „
0.01 (1 c.c. „ = 0.01 mgr. NH_3)
„ „ „ = 0.088 mgr. NH_3
2
1000 c.c. (1 lit.) „ = 0.176 mgr. „ or 0.0176 centigramme NH_3 per litre
= 0.0176 part per 100,000
(0.0176 × 0.7 = 0.01232 grain per gallon.)

Wanklyn Nesslerises the first 50 c.c. of distillate in estimating *free* ammonia, and adds $\frac{1}{3}$ to estimate all the free ammonia in 500 c.c. of water. The albuminoid ammonia is estimated per 50 c.c. as before.

E.g., 500 c.c. are taken:

1st 50 c.c. distillate = 1.5 c.c. standard solution (1 c.c. = 0.01 mgr.);

$\frac{1}{3}$ of 1.5 = 0.5 c.c. 1.5 + 0.5 = 2.0 c.c. standard for 500 c.c. of water.

2.0 × 0.01 = 0.02 mgr. NH_3 in 500 c.c. or 0.04 mgr. NH_3 in 1000 c.c. (1 litre) = 0.004 centigramme NH_3 per litre or part per 100,000.

(In waters containing much organic matter the addition of $\frac{1}{3}$ to the free ammonia in the first 50 c.c. does not represent all the ammonia.)

Albuminoid ammonia is Nesslerised in the usual way—each 50 c.c. separately.

Parkes and de Chaumont distilled off 130 to 150 c.c. of the water for estimating free or albuminoid ammonia, and took 100 c.c. of the distillate for Nesslerising (or 50 c.c. diluted up to 100 c.c. with ammonia-free distilled water if much ammonia, ascertained by a preliminary test of the distillate, were present).

E.g., 250 c.c. of water were taken and 140 c.c. distilled over, the last part being free from ammonia.

100 c.c. of the distillate = 3.5 c.c. standard ammon. chloride (1 c.c. = 0.01 mgr. NH_3).

100 : 140 : : 3.5 x. x = 4.9 c.c. solution for 250 c.c. of water.

4.9 × 0.01 = 0.049 mgr. NH_3 in 250 c.c. of water.

$0.049 \times 4 = 0.196$ mgr. NH_3 per litre, or 0.0196 centigramme per litre = 0.0196 part NH_3 per 100,000 ($0.0196 \times 0.7 = 0.01372$ grain per gallon).

Of the three methods the best is to distil and test each 50 c.c. separately both for free and albuminoid ammonia.

If in the last case 1 c.c. standard solution = 0.017 mgr. NH_3,

100 : 140 : : 3.5 : x. $x = 4.9$ c.c. $4.9 \times 0.017 \times 4 = 0.3332$ mgr. per litre = 0.03332 centigramme per litre,

or part per 100,000 of NH_3.

If there is little free ammonia, which may come off in the first 50 c.c. of distillate, it is a waste of time to distil over 130 c.c. *en bloc.*

Dissolved Oxygen in Water.

I. Amount expressed as milligrammes per litre.

Thresh's Method.—The iodine liberated from an acid solution of sodium nitrite and potassium iodide, in the presence of oxygen, is estimated by titrating with a standard solution of sodium thiosulphate giving a colour-reaction with starch.

Standard solution of sodium thiosulphate. Strength : 1 c.c. = 0.25 mgr. of oxygen.

$$2Na_2S_2O_3.5H_2O + I_2 = 2NaI + Na_2S_4O_6$$

(496)

I_2 (monovalent) corresponds to O (divalent).

(16)

16 grammes O : 0.25 gramme O : : 496 grammes thiosulphate : x.

$x = \frac{124}{16} = 7.75$ grammes thiosulphate.

$\therefore$ 7.75 grammes per litre = 0.25 mgr. O per 1 c.c.

Let e = c.c. of standard thiosulphate used in estimating the amount of oxygen in the sample of water.

f = capacity of stoppered tube in c.c. – 2 c.c.

("– 2 c.c." = deduction for 1 c.c. sodium-nitrite-and-potassium-iodide solution + 1 c.c. dilute sulphuric acid.)

b = "correction" in c.c. for oxygen contained in these two solutions.

d = " " " " " thiosulphate solution itself.

(At ordinary "laboratory temperatures" = 0.31.)

Amount of dissolved oxygen in mgr. per litre = $\frac{1000}{4f} \times (e - b - ed)$.

If the capacity of the "separatory tube" be 252 c.c., $f = (252 - 2) + \frac{1000}{4f} = 1$, and the formula becomes $(e - b - ed)$.

Example.—252 c.c. of shallow-well water in "separatory tube" used 10.22 c.c. thiosulphate; $b = 2.1$ c.c. $d = 0.31$.

$$\frac{1000}{4(252-2)} \times \{10.22 - 2.1 - (10.22 \times 0.31)\} = 1 \times \{10.22 - 2.41682\}$$

$= 7.8$ milligrammes O per litre.

II. Expressed volumetrically as c.c. per litre.

Winckler's Method.—A solution of manganous chloride is oxidised to manganic chloride, and the iodine, liberated by the action of potassium iodide, is estimated by titration with a standard solution of sodium thiosulphate with starch as the indicator.

Standard solution of sodium thiosulphate. Strength: 1 c.c. = 0.1 c.c. oxygen.

$2Na_2S_2O_3{\cdot}5H_2O + I_2 = 2NaI + Na_2S_4O_6$. $I_2 = O = 11.16$ litres.
(496)

11.16 : 1 : : 496 : x. $x = 44.4$ grammes thiosulphate = 1 litre oxygen.

44.4 grms. thiosulphate per litre : 1 c.c. = 1 c.c. oxygen.

4.44 ,, ,, ,, ,, = 0 1 c.c. ,,

$MnCl_2$ solution = 40%. KI 10 grms. in 100 c.c. of 8*N*.NaHO.

Example.—After adding to the water 2 c.c. manganous chloride, and 2 c.c. potassium iodide-and-caustic soda solutions, and finally 3 c.c. strong HCl:

250 c.c. water = 20.5 c.c. standard thiosulphate solution.

∴ 1000 c.c. water 82 c.c. ,, ,, ,,

1 c.c. standard = 0.1 c.c. oxygen.

∴ ,, (1 litre) water = 8.2 c.c. dissolved oxygen.

Oxidisable Organic Matter.

I. Tidy's Process.—Oxygen absorbed from standard potassium permanganate is estimated by titration with sodium thiosulphate.

Standard solution of potassium permanganate. Strength: 10 c.c. = 1 mgrm. of oxygen.

$4KMnO_4 + 6H_2SO_4 = 2K_2SO_4 + 4MnSO_4 + 5O_2 + 6H_2O$.
(632) (160)

160 : 1 : : 632 : x. $x = 3.95$ grms. $KMnO_4 = 1$ grm. oxygen.

3.95 grms. per litre = 1 grm. O per litre : 1 c.c. = 1 mgr. oxygen.

0.395 grm. ,, = 0.1 ,, ,, : 10 c.c. = 1 ,,

Sodium thiosulphate solution: usually 1 grm. $Na_2S_2O_3{\cdot}5H_2O$ per litre.

If the required strength is "40 c.c. = 1 mgr. O": 16 : 1 : : 496 : x. $x = 31$ grms. = 1 grm. O. 3.1 grm. per litre = 1 mgr. O per litre, 3.1 grms. in 4 litres : 40 c.c. = 1 mgr. O.

Example (1).—250 c.c. water at 26.7° C. (80° F.) + 10 c.c. standard permanganate + 10 c.c. dilute H_2SO_4 = 27.5 c.c. thiosulphate solution.

250 c.c distilled water similarly treated = 39.3 c.c. thiosulphate solution.

= 10 c.c. standard permanganate.
= 1 mgr. oxygen.

39.3 − 27.5 = 11.8 c.c. thiosulphate solution equivalent to oxygen taken up by organic matter.

39.3 : 11.8 : : 1 mgr. O : x. x = 0.3 mgr. O taken up by 250 c.c. of water, = 1.2 mgr. per litre = 0.12 centigramme of oxygen per litre, or parts per 100,000.

(2) 200 c.c. distilled water treated as above = 38.0 c.c. thiosulphate solution.

= 10 c.c. standard permanganate.
= 1 mgr. oxygen.

200 c.c. sample water treated as above = 22.7 c.c. thiosulphate solution.

38.0 − 22.7 = 15.3 c.c. thiosulphate representing oxygen absorbed by organic matter.

38.0 : 15.3 : : 1 : x. x = 0.4 mgr. O absorbed in 200 c.c. of water.
= 0.2 „ „ 100 c.c. „
or 0.2 part of oxygen per 100,000.

Nitrites.

Griess' Test.—A colour reaction by nitrites acting on metaphenylene-diamine and dilute sulphuric acid. Matched by standard solution of potassium- or sodium-nitrite. Strength 1 c.c. = 0.01 mgrm. N_2O_3.

Example.—100 c.c. water + 1 c.c. metaphenylene-diamine solution + 1 c.c. dilute H_2SO_4 were matched by 8.5 c.c. standard nitrite in 100 c.c. distilled water similarly treated.

1 c.c. standard = 0.01 mgr. N_2O_3.
∴ 8.5 c.c. = 0.085 mgr. „ in 100 c.c. of water.
= 0.085 part „ per 100,000.

$N_2 = 28$. $N_2O_3 = 76$. $N_2 : N_2O_3 : : 28 : 76$. $N_2 = \frac{28}{76}$ of $N_2O_3 = 0.37 \times N_2O_3$.

8.5 c.c. = 0.085 × 0.37 = 0 031 part per 100,000 of nitrogen.

Nitrates and Nitrites.

By the "zinc-copper couple," or aluminium and caustic soda method, all oxidised nitrogen = ammonia; this is estimated by Wanklyn's process.

Example.—500 c.c. water originally contained 0.006 part per 100,000 of free ammonia.

250 c.c. from the same sample after the zinc-copper process by Nesslerisation = 0.28 part per 100,000 of ammonia. 0.28 − 0.006 = 0.274 part of ammonia per 100,000 from nitrates and nitrites.

To express as "nitrogen in nitrates and nitrites": N = 14.

$$NH_3 = 17. \quad N : NH_4 :: 14 : 17. \quad N = \frac{14}{17} NH_3.$$

$$\therefore\ 0.274 \times \frac{14}{17} = 0.23 \text{ nitrogen per } 100{,}000 \text{ of water.}$$

Nitrates.

Phenol-Sulphonic Method.—Colour-reaction obtained by acting on nitrates with phenol-sulphonic acid and ammonia, and matching the colour with a standard solution of potassium nitrate similarly treated.

Standard potassium nitrate solution. Strength: 1 c.c. = 0.1 mgr. nitrogen.

$$\underset{(101)}{KNO_3} = \underset{(14)}{N}. \quad \frac{101}{14} = 7.22.$$

$\therefore$ 0.722 gm. KNO_3 per litre. 1 c.c. = 0.1 mgr. N.

Example.—(A) 25 c.c. water-sample evaporated to dryness + 2 c.c. phenol-sulphonic acid + 20 c.c. (or *q.s.*) strong NH_3 solution. } Made up to 50 c.c. with distilled water in Nessler-glass.

(B) 10 c.c. standard potassium-nitrate solution + 2 c.c. phenol-sulphonic acid + 20 c.c. (or *q.s.*) strong NH_3 solution. } ,,

The latter (B) gave the darker colour, and was carefully "poured off" from the Nessler-glass till 20 c.c. remaining had the same colour as the contents in the other glass (A).

$\therefore$ $\frac{20}{50}$ of 10 c.c. = 4 c.c. standard nitrate solution matched colour due to nitrates in 25 c.c. of sample-water.

1 c.c. = 0.1 mgr. N. $\therefore$ 4 c.c. = 0.4 mgr. N in 25 c.c. of sample-water.

= 1.6 mgr. N in 100 c.c. of sample-water.

or 1.6 parts ,, 100,000 ,, ,,

Quantitative Estimation of Lead, Copper, Iron and Zinc.

Standard Solution of Lead Acetate.

$Pb2(C_2H_3O_2).3H_2O = 379.Pb = 207.$ $\frac{379}{207} = 1.83$ lead acetate.

1.83 grms. acetate per litre = 1 grm. lead per litre.
1 c.c. = 1 mgr. of lead. (0.183 grm. per litre : 1 c.c. = 0.1 grm. Pb.)

Standard Solution of Copper Sulphate.

$CuSO_4.5H_2O = 249.2.$ $Cu = 63.2.$ $\frac{249.2}{63.2} = 3.94$ copper sulphate.

3.94 grms. per litre = 1 grm. copper per litre.
1 c.c. = 1 mgr. of copper. (0.394 grm. per litre: 1 c.c. = 0.1 grm. Cu.)

Standard Solution of Ferrous-Ammonium-Sulphate.

$Fe2(NH_4).2(SO_4).6H_2O = 392.$ $Fe = 56.$ $\frac{392}{56} = 7$ ferrous ammonium sulphate.

7 grms. per litre = 1 grm. iron per litre. 1 c.c. = 1 mgr. iron (0.7 grm. per litre. 1 c.c. = 0.1 mgr. Fe.)

Standard Solution of Zinc Sulphate.

$ZnSO_4.7H_2O = 287.$ $Zn = 65.$ $\frac{287}{65} = 4.415.$

4.415 grms. per litre = 1 grm. zinc per litre. 1 c.c. = 1 mgr. zinc.
(0.4415 „ „ „ 1 c.c. = 0.1 mgr. Zn.)

EXAMPLE.—200 c.c. sample water *evaporated down to* 100 *c.c.* (containing lead)
+ 2 drops acetic acid
+ 2 drops concentrated ammonium-sulphide solution.
} In 100 c.c. Nessler-glass.

Is matched in tint by 100 c.c. distilled water
+ 1.5 c.c. standard lead-acetate solution (1 c.c. = 1 mgr. Pb.)
+ 2 drops acetic acid
+ 2 drops ammonium-sulphide solution.
} „

$\therefore$ $1.5 \times 0.1 = 0.15$ mgr. of lead in 200 c.c. of sample-water.
$= 0.075$ „ „ „ „ 100 „ „ „ „
= „ part per 100,000 ($0.075 \times 0.7 = 0.525$ grain per gallon.)

CHAPTER VI.

SOIL.

Percentage of Air in Soil.

Loose Soil.—c.c. of dry soil : 100 : : c.c. of water used : percentage of air.

$$\text{Percentage of air} = \frac{\text{c.c. of water used}}{\text{c.c. of dry soil}} \times 100.$$

EXAMPLE.

Soil dried at 100° C. and powdered, measured in burette = 25 c.c.

Water from second burette rising to upper level of soil = 7·5 c.c.

$$25 : 100 :: 7{\cdot}5 : x. \quad x = \frac{7{\cdot}5}{25} \times 100 = 30\ \% \text{ of air.}$$

Porous rock.

Let W_a = weight of dry rock in air.

W_w = „ „ „ „ „ water.

W_s = „ „ saturated rock in air.

$W_a - W_w$ = loss of weight in water (weight of an equal volume of water).

$W_s - W_a$ = weight of water absorbed.

Loss of weight in water : 100 : : weight of water absorbed : percentage of air,

or $\dfrac{\text{Weight of water absorbed}}{\text{Loss of weight in water}} \times 100 = \text{percentage of air.}$

EXAMPLE.

Weight of dry rock in air = 112 grms.

„ „ rock „ water = 72 „

„ „ saturated rock in air = 125 grms.

112 − 72 = 40 grms. loss of weight in water.

125 − 112 = 13 „ weight of water absorbed.

40 : 100 : : 13 : percentage of air.

$\frac{13}{40} \times 100 = 32{\cdot}5\ \%$.

Percentage of Moisture in Soil.

"Moisture" = air + water.

Weight of soil before drying ; 100 : : loss of weight after drying ; percentage of moisture,

$$\text{Percentage of moisture} = \frac{\text{loss of weight after drying}}{\text{weight before drying}} \times 100.$$

EXAMPLE.—Moist soil = 10 grms.

After drying at 100° = 6.5 grms. Loss of weight = 10.0 − 6.5 = 3.5 grms.

10 : 100 : : 3.5 : Percentage of moisture = 35.

Specific Gravity of Soil.

1. **"Apparent Specific Gravity."** (Soil containing air.)

$$= \frac{\text{Weight of known volume of soil}}{\text{Weight of an equal volume of water}} \text{ (water = 1).}$$

EXAMPLE.—Weight of dry cylinder + dry soil = 1206 grammes.
" " cylinder + distilled water = 943 "
" " dry cylinder (empty) = 387 "
1206 − 387 = 819 grammes = weight of soil.
943 − 387 = 556 " = " " water.
556 : 1 : : 819 : apparent sp. gr. = 1.473 (water = 1).

2. **True Specific Gravity** $= \frac{\text{Weight of soil.}}{\text{Weight of an equal volume of water}}$
(= weight of water displaced by soil).

EXAMPLE.—Weight of soil = 5 grammes.
Weight when sp. gr. bottle is full of distilled water = 25 grammes.
" of " " empty = 12.25 "
" " " " + soil + distilled water (both boiled and freed of air) = 40.2 "
40.2 − 12.25 = 27.95 grms. (soil and water in bottle)
(5 + 25) − 27.95 = weight of water displaced = 2.05 grammes.

$$\text{True sp. gr.} = \frac{5}{2.05} = 2.4 \text{ (water = 1).}$$

3. **Pore-volume**, or Volume of soil occupied by air :

$$\frac{\text{Apparent sp. gr.}}{\text{True sp. gr.}} = \frac{1.473}{2.4} = 0.6 \text{ of total bulk occupied by soil.}$$

1 − 0.6 = 0.4 or 40 % = "pore-volume."

4. **Water Capacity of Soil** (Percentage of pore-volume that can be filled with water by capillarity).

Weight of dry cylinder (with perforated base) = 377 grammes.
" " " + dry soil = 1102 "
" " " + wet " = 1277 "

1102 − 377 = 725 grammes dry sand in cylinder.
1277 − 1102 = 175 " water absorbed by 725 " dry sand.

725 : 100 : : 175 : x = 28 per cent. weight of water absorbed.

"Pore-volume = 40 per cent." ∴ 40 : 28 : : 100 : x = 70 per cent. of pore-volume = water capacity of soil.

CHAPTER VII.

SEWERAGE.

Circular Pipes.

"Sectional area": that of a transverse section of the fluid, or of the interior of a pipe $= \pi r^2$ (the area of a circle).

"Wetted perimeter": length of arc, in a transverse section, wetted by the contained fluid.

$$\text{Hydraulic mean depth} = \frac{\text{Sectional area of fluid}}{\text{Wetted perimeter}}.$$

In a circular pipe the "H.M.D." is always $\frac{1}{4}$ the diameter, whether the sewer is running full or half-full.

If running full: Sectional area of fluid = internal circular area of pipe $= \pi r^2$. Wetted perimeter = circumference of circle $= 2\pi r$.

$$r = \text{radius} = \frac{\text{Diameter}}{2}.$$

$$\text{H.M.D.} = \frac{\pi r^2}{2\pi r} = \frac{r}{2} = \frac{\text{Diameter}}{4}.$$

$$\text{If running } \tfrac{1}{2} \text{ full: H. M. D.} = \frac{\frac{\pi r^2}{2}}{\frac{2\pi r}{2}} = \frac{\pi r^2}{2\pi r} = \frac{\text{Diameter}}{4}.$$

Velocity of Flow: $V = 55\sqrt{2\ D \times F}$.

Eytelwein's Formula founded on that of De Chezy.

V = velocity *in feet* per minute.
D = Hydraulic mean depth *in feet.*
F = fall *in feet* per mile.
V × Sectional area in feet = Discharge per minute in cubic feet.

Example.—(1) A 9-inch drain is to have a velocity of 3 feet per second. The required fall or "gradient" is to be calculated.
H.M.D. $= \frac{1}{4}$ of 9 inches $= \frac{3}{16}$ foot.
Velocity = 3 feet per second = 180 feet per minute.

By the above formula:

$$55\sqrt{2 \times \tfrac{3}{16} \times F} = 180. \quad \sqrt{\tfrac{3}{8}F} = \frac{180}{55}. \quad \tfrac{3}{8}F = \left(\frac{180}{55}\right)^2$$

$$F = \frac{1296}{121} \times \frac{8}{3} = \frac{3456}{121} = 28.56 \text{ feet per mile.}$$

(1 mile = 5280 feet). $\therefore$ fall = 1 in 185.

2. A 6-inch drain has a gradient of 1 in 60. What is the velocity of flow and discharge per second if the pipe is half full?

$$60 : 5280 :: 1 : x = 88 \text{ feet per mile.}$$

H. M. D. = $\frac{1}{4}$ of $\frac{1}{2} = \frac{1}{8}$ foot.

$$V = 55\sqrt{2 \times \tfrac{1}{8} \times 88}$$

$$V = 55\sqrt{22}.$$

$$= 55 \times 4.69 = 258.0 \text{ feet per minute.}$$

$\therefore$ velocity = 4.3 „ „ second.

If the drain is running full the sectional area = πr^2; 6-inch diameter = $\frac{1}{4}$ foot radius;

sectional area = $3.1416 \times (\frac{1}{4})^2$ sq.ft. = $3.1416 \times \frac{1}{16}$ sq.ft. = 0.196 sq.ft.

When half full the sectional area = 0.068 square foot.

Discharge = sectional area × velocity = 0.098 × 4.3.

= 0.4214 cubic foot per second.

(25.28 per minute; 1516.8 per hour)

= 9404 gallons per hour (1 cubic foot = 6.2 gallons).

(3) A circular sewer having a fall of 1 in 200 has a current velocity of 2.5 feet per second. Calculate the necessary diameter.

Fall = 1 in 200; per mile : 200 : 1 : : 5280 : $x = 26.4$ feet.

Velocity 2.5 feet per second = 150 feet per minute.

$$\text{H.M.D.} = \frac{\text{diameter}}{4}$$

$$\therefore \quad 150 = 55\sqrt{2 \times \frac{\text{diameter}}{4} \times 26.4}$$

$$150 = 55\sqrt{13.2 \times \text{diameter}}.$$

$$\left(\frac{150}{55}\right)^2 = 13.2 \times \text{diameter in feet.}$$

$$\left(\frac{30}{11}\right)^2 = 13.2 \times \quad „ \quad „ \quad „$$

$$\frac{900 \times 12}{121 \times 13.2} = \text{diameter in inches} = 7.3.$$

Maguire's Formula: To calculate the fall or gradient in *circular drains* and sewers (diameter 3″ – 10′). Diameter in inches × 10:

4″ = 1 in 40; 6″ = 1 in 60; 9″ = 1 in 90, &c.

When drain-pipes are running half- or more than half-full the incline may be less; usually they are not more than $\frac{1}{4}$ or $\frac{1}{3}$ full, and the inclines given should be carried out (W. C. Tyndale.)

Bailey Denton and Baldwin Latham recommended smaller gradients:

Diameter.		Velocity per second. 2 feet.	3 feet.	4 feet.	
4	Fall = 1 in	194	92	53	Running full or $\frac{1}{2}$ full.
6	,,	292	137	80	
9	,,	437	206	119	
12	,,	583	275	159	

Velocity in feet × inclination = length of sewer.

E.g., velocity = "4 feet per second." Fall = "1 in 119."

Required length of sewer = 4 × 119 = 476 feet.

Civil engineers in planning drainage systems are guided by the following practical rules:

As regards main sewers:

1. **On the Separate System**—admitting sewage proper and rainfall from back roofs and yards only: The allowance is 40 gallons *per head*, or 200 gallons per house, made up as follows:

25 gallons per head for water-supply (which practically all goes into the sewer); 15 gallons per head for rainfall.

The usual allowance per head for backyards and roofs (in the separate system) is 100 square feet, and $\frac{1}{4}$ inch of rain upon an impervious surface of this extent yields 13 gallons. Deducting $\frac{1}{4}$ for loss by evaporation and absorption (= 3.25 gallons) the actual flow-off is 9.75 or $9\frac{3}{4}$ gallons. The allowance for rainfall is purposely taken high to allow for thunderstorms. 15 gallons = $\frac{3}{8}$ inch of rainfall daily on a surface of 100 square feet.

As the flow of sewage is variable, half the total daily volume is allowed to be discharged in 6 hours, and sewers are constructed of such a size that will discharge this amount when running *half full.*

The Local Government Board requires that all sewers on the separate system shall be capable of discharging six times the dry-weather flow when running full; after which storm-water overflows may discharge the excess into the nearest water-course. The dry-weather flow of sewage is practically the volume of the drinking-water supply—usually calculated at 25 gallons per head. 25 × 6 = 150 gallons. This is what a sewer must be capable of discharging at a minimum velocity of 2 feet per second.

2. **On the Combined System**: 1. The areas to be estimated (from Ordnance maps or actual measurements) are:

(*a*) the area built over, and (*b*) the area of the roads.

2. Allowance must be made for the maximum known rainfall of the district for 24 hours, *taking it at the highest recorded rate per hour.*

3. Add to this the flow of sewage proper—*i.e.* 25 gallons per head.

The result is the total volume to be discharged per hour, and from this the size of the sewer is determined.

Allowing for a rainfall of $1\frac{1}{4}$ inches per hour, a 4-inch drain laid at a uniform inclination of 1 in 60 has a discharging capacity sufficient for the drainage of a building containing 20 inhabitants, and an area of 11,000 square feet; a 5-inch drain for 50 inhabitants, and an area of 19,000 square feet; and a 6-inch drain for 100 inhabitants, and an area of 30,000 square feet (Lawford).

I am indebted to Mr. G. Maxwell Lawford, M. Inst. C.E., of London, for the following data and for the Scale-Drawing:

Lawford's Formulæ for the Velocity and Discharge of Sewers and Water-Mains:

1. For velocity: $V = \frac{2g}{m} \times R^{0.7} \times S^{0.5}$.

   $(R^{0.7} = R^{\frac{7}{10}} = \sqrt[10]{R^7}$ and $S^{0.5} = S^{\frac{1}{2}} = \sqrt{S})$

2. For discharge: $Q = \frac{2g}{m} \times R^{2.7} \times S^{0.5} \times 4695.7$.

   V = velocity in feet per second.
   g = acceleration of gravity = 32.2 feet per second.
   m = coefficient for roughness of surface.
   = 0.5 for new or clean asphalted cast-iron pipes, glazed stoneware pipes and glazed or vitrified brickwork, &c.
   = 0.55 for cast-iron pipes after some use, well laid concrete tubes, &c.
   = 0.6 for encrusted iron pipes, rough brick-work, &c.
   R = hydraulic mean radius (or "depth") in feet.
   $= \frac{\text{diameter}}{4}$ for circular sewers, pipes, &c.
   $= \frac{\text{sectional area}}{\text{wetted perimeter}}$ for egg-shaped sewers.
   S = slope of water surface.
   $= \frac{\text{head of water in feet}}{\text{length of pipe or sewer in feet}}$ = hydraulic mean gradient.
   Q = quantity of water or sewage discharged in gallons per minute when running *full.*

Example.—What diameter is required for a glazed stoneware pipe sewer to provide for a population of 10,000, the available fall being 1 in 500?

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Total daily discharge = 10,000 × 25 × 6.
= 1,500,000 gallons per 24 hours.

Maximum flow = half in 6 hours.
= 750,000 gallons in 6 hours.
= 2083 gallons per minute = Q.

$\frac{2g}{m} = \frac{64.4}{0.5} = 128.8$. $S = \frac{1}{500} = 0.002$. $S^{0.5} = \sqrt{0.002} = 0.0447$.

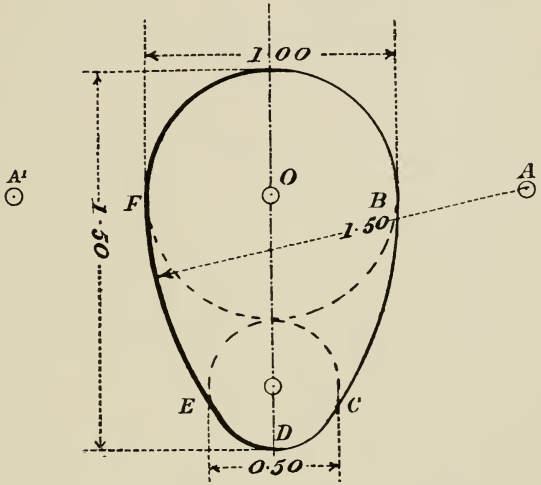

FIG. 24.—Egg-Shaped Sewers. Diagram showing proportions of dimensions and radii. The horizontal diameter being 1, the diameter of the invert is 0.5, the total depth is 1.50 and the radii of the sides is 1.50.

OA = OD = OA¹ = 1.00.
Curve FE = arc of circle having centre at A, and radius AF = 1.50.
Similarly, curve BC = arc of circle having centre at A¹.

$$R = \sqrt[2.7]{\frac{2083}{128.8 \times 0.0447 \times 4695.7}} = 0.383.$$

and $0.383 \times 4 = 1.53$ feet = 18 inches (nearly).

∴ diameter required = 18 inches.

EXAMPLE.—What size of brick sewer is required for a population of 80,000, the available fall being 1 in 1000?

Maximum flow (calculated as above) = 16,666 gallons per minute.

$m = 0.55$. $\frac{2g}{m} = 117.09$. $S = 0.001$. $S^{0.5} = \sqrt{0.001} = 0.0316$.

$$R = \sqrt{\frac{16{,}666}{117.09 \times 0.0316 \times 4695.7}} = 0.9844 \times 4 = 3.9276$$

or 4 feet diameter.

An egg-shaped sewer of the same sectional area
= 5 feet × 3 feet 4 inches.
Deducting $\frac{1}{6}$ from diameter of circular sewer (*vide supra*)
= 4 feet less 8 inches = 3 feet 4 inches.

CHAPTER VIII.

DIET AND ENERGY.

DATA necessary (1) a standard diet, "ordinary," "rest," or "hard work" for the energy required.

(2) the percentage composition of the food.

Water-free ordinary diet for an adult (= 300 foot-tons of energy * daily).

	Ounces.	
Proteids . .	4.5	+ 2 ounces for "hard-work."
Fats . .	3.0	− „ „ „ "rest."
Carbo-hydrates .	14.0	
Salts . .	1.0	+ 0.5 „ „ "hard-work."
		− „ „ „ "rest."
	22.5 ounces.	

In terms of nitrogen and carbon:

	Grains.	Grains.
Diet for rest . . .	200	4000
„ ordinary work .	300	5000
„ hard work . .	400	6000

Percentage composition of foods, &c.:

	Bread.	Milk.	Meat. (uncooked)	Butter.	Cheese.	Oatmeal.
Water . .	40.0	88.0	75.0	12.0	37.0	
Proteids . .	8.0	4.0	15.0	1.0	33.5	16.5
Fats . . .	1.5	3.0	8.5	84.5	24.0	6.5
Carbo-hydrates .	49.0	4.3	—	1.0	—	63.0
Salts . .	1.5	0.7	1.5	1.5	5.5	2.5
	100.0	100.0	100.0	100.0	100.0	

Food for a child:

Age 2 years: $\frac{3}{10}$ (0.3) of the adult's standard diet for ordinary work.

* "Foot-ton" = amount of energy that will raise 1 ton 1 foot in height.

Age 3–5 years: $\frac{4}{10}$ (0.4) of the adult's standard diet for ordinary work.

Age 6–9 years: $\frac{5}{10}$ ($\frac{1}{2}$) of the adult's standard diet for ordinary work.

EXAMPLE.—**To Calculate the Quantity of Bread, Butter and Cheese necessary for an ordinary Day's Work of 300 Foot-tons of Energy.**

	Proteids.	Fats.	Carbo-hydrates.	
Standard ordinary diet	4.5	3.0	14.0	*per cent.* (= total diet).
Composition of bread .	8.0	1.5	49.0	,,
,, ,, butter	1.0	85.0	—	,,
,, ,, cheese	33.5	24.0	—	,,

oz. oz. prds.

Let x = oz. bread—by Simple Proportion: $100 : x :: 8$: proteids in bread.

$$\frac{8x}{100} = \quad ,, \quad ,,$$

Let y = oz. butter ,, ,, $100 : y :: 1$: ,, butter.

$$\frac{y}{100} = \quad ,, \quad ,,$$

Let z = oz. cheese ,, ,, $100 : z :: 33.5$: ,, cheese.

$$\frac{33.5z}{100} = \quad ,, \quad ,,$$

$$\text{and } \frac{8x}{100} + \frac{y}{100} + \frac{33.5z}{100} = 4.5 \text{ (proteids).}$$

$$\text{Similarly } \frac{1.5x}{100} + \frac{85y}{100} + \frac{24z}{100} = 3 \text{ (fats).}$$

$$\text{and } \frac{49x}{100} = 14 \text{ (carbo-hydrates).}$$

Reducing these fractions (multiplying by 100):

(1) $8x + y + 33.5z = 450.$

(2) $1.5x + 85y + 24z = 300.$

(3) $49x = 1400.$ $x = 28.6$ ounces of bread.

Replacing in (1) the value of x:

$(8 \times 28.6) + y + 33.5z = 450.$

(A) $y + 33.5z = 221.$

Replacing in (2) the value of x:

$(1.5 \times 28.6) + 85y + 24z = 300.$

(B) $85y + 24z = 257.$

Multiply (A) by 85: $85y + 2847.5z = 18785.$

Subtract (B): $85y + 24.0z = 257.$

$2823.5z = 18528$

$z = 6.5$ ounces cheese.

Replace in (2) the respective values of x (28.6) and z (6.5):

$$\therefore 42.9 + 85y + 156 = 300.$$
$$85y + 198.9 = 300.$$
$$y = 1.2 \text{ ounces butter.}$$

The required quantities are: 28.6 ounces bread; 1.3 ounces butter; 6.5 ounces cheese.

To Calculate if 1½ Pounds of Bread and 60 Ounces of Milk will be a sufficient Diet for a man doing an ordinary Day's Work.

	Proteids.	Fats.	Carbo-hydrates.
100 oz. bread =	8 oz.	1.5 oz.	49 oz.
24 „	$= \frac{8 \times 24}{100} = 1.92$ oz.	$\frac{1.5 \times 24}{100} = 0.36$ oz.	$\frac{49 \times 24}{100} = 11.7$ oz.
100 oz. milk =	4.0 „	3.0 „	4.3 „
60 „	$= \frac{4 \times 60}{100} = 2.4$ „	$\frac{3 \times 60}{100} = 1.8$ „	$\frac{4.3 \times 60}{100} = 2.5$ „
Total (1½ lb. and 60 oz.) =	4.32 „	2.16 „	14.2 „
Ordinary diet =	4.50 „	3.00 „	14.0 „

The above diet is therefore somewhat deficient in proteids and fats, but is more than enough in carbo-hydrates.

To Calculate the Amount of Meat and Bread necessary for a Daily Diet in Terms of Nitrogen and Carbon.

	Nitrogen.	Carbon.
Ordinary day's diet (moderate work) =	300 grains.	5000 grains.
1 pound of meat =	190 „	1900 „
1 „ bread =	90 „	2000 „

Let x = pounds of meat required (1) $190x + 90y = 300$ grains N.

Let y = pounds of bread required (2) $1900x + 2000y = 5000$ grains C.

Multiply (1) by 10: $1900x + 900y = 3000$

Subtract the result from (2): $1100y = 2000$.

$$y = 1.8 \text{ pounds bread.}$$

Substituting the value of y in (1) $190x + 162 = 300$.

$$x = 0.7 \text{ pound} = 11.2 \text{ ounces meat.}$$

Energy evolved.

Internal work of the body (circulation, respiration, &c.) = 2800 foot-tons.

External „ „ „ (average)	Light	150 foot-tons.
	Moderate	300 „
	Hard	450 „
	Laborious	600 „

De Chaumont's Formula for calculating external Work:

Ordinary $= (300 \times 5) = 1500$ foot-tons.

Above „ $= (300 \times 5) + \left(300 \times \frac{7}{2}\right) = 1500 + 1050) = 2550$ ft.-tons.

Hard $= (300 \times 5) + \left(300 \times \frac{7}{2}\right) + \left(300 \times \frac{9}{4}\right) + 1350 = 3600$ „

Laborious $= (300 \times 5) + \left(300 \times \frac{7}{2}\right) + \left(300 \times \frac{9}{4}\right) + \left(300 \times \frac{11}{8}\right) =$ $3600 + 412.5 = 4012.5$ foot-tons.

In round numbers $300 \times \left(5 + \frac{7}{2} + \frac{9}{4} + \frac{11}{8} + \ldots\right) = 300 \times 14 = 4200$.

∴ Total external work $= 4200$ foot-tons.
„ internal „ $= 2800$ „

7000 „

The food necessary for 450 foot-tons of productive work must provide 2550 foot-tons of potential energy for external work + 2800 foot-tons for internal work = 5350 foot-tons.

Therefore $\frac{450}{2550}$, or $\frac{1}{5}$ of potential energy for external work, is available for productive labour.

De Chaumont's Formula for productive Work:

Ordinary: $300 \times 1 = 300$ foot-tons.
Above „ „ „ $+(300 \times \frac{1}{2}) = 450$ foot-tons.
Hard: „ „ „ $+(300 \times \frac{1}{4}) = 525$ foot-tons.
Laborious: „ „ „ „ $+(300 \times \frac{1}{8}) =$ 562.5 foot-tons.

Example.—A man is doing light work (*e.g.* 250 foot-pounds); how much cooked meat would he require to provide the necessary amount of energy?

100 ounces of cooked meat contain 28 ounces of proteids and 15 ounces of fats.

1 ounce proteid =	173	foot-tons	potential	energy.
1 ounce fat =	378	„	„	„
$28 \times 173 =$	4844	„	„	„
$15 \times 378 =$	5670	„	„	„
100 ounces cooked meat =	10514	„	„	„
Deducting 2800 for internal work	2800			
	7714	„	„	„

available for external work, and of this only $\frac{1}{5}$ is represented by actual work, or about 1543 foot-tons of *actual work*.

Let x = ounces of meat necessary for 250 foot-pounds of actual work:

$$1543 : 250 : : 100 : x = 16.2 \text{ ounces cooked meat.}$$

(By a previous example 28.6 ounces bread, 1.3 ounces butter and 6.5 ounces cheese were found to be sufficient for 300 foot-tons of work, therefore 23.6 ounces bread, 1.8 ounces butter, and 5.4 ounces cheese will provide 250 foot-tons of work.)

Energy expressed in terms of heat-value, or "calorific capacity."

1 calorie = amount of heat necessary to raise 1 gramme of water 1° C.

$\frac{4}{5}$ or $\frac{5}{6}$ total potential heat = actual heat.
$\frac{1}{5}$ or $\frac{1}{6}$ „ „ = „ work.

Potential energy available from diet:

Proteids.			Fats.		
	1 ounce.	1 gramme.		1 ounce.	1 gramme.
Foot-tons	173	calories 4.1	Foot-tons	378	calories 9.3

Carbo-Hydrates.		
	1 ounce.	1 gramme.
Foot-tons	138	calories 4.1

To Calculate the Heat-value of a Food in calories.

Example.—Oatmeal contains per 100 parts (taken as grammes)

Proteids	12.5	(1 gramme = 4.1 calories)	=	12.5 × 4.1	=	51.25	calories.
Fats	6.5	„	= 9.3	„	=	6.5 × 9.3 = 60.45	„
C.-H.	63.0	„	= 4.1	„	=	6.3 × 4.1 = 258.30	„
						370.00	„

Calculation of Mechanical Work.—Height × weight = foot-pounds or foot-tons of work.

Let W = weight in pounds.
H = vertical height in feet.
W × H = foot-pounds of work.
If H = height in miles, 5280 feet = 1 mile:

$$W \times 5280\ H = \textit{foot}\text{-pounds of work.}$$

To express foot-pounds as foot-tons: 2240 lbs. = 1 ton.

$$2240 : (W \times 5280) : 1 : x = \frac{W \times 5280}{2240} \text{ foot-tons.}$$

Allowance made for "traction" or resistance:

Moving along a level at 3 miles per hour = lifting the entire weight vertically $\frac{1}{20}$ of the distance traversed, or lifting $\frac{1}{20}$ weight the whole distance At 4 miles per hour this "co-efficient of traction" becomes $\frac{1}{17}$; at 5 miles, $\frac{1}{14}$.

Energy at 3 miles per hour along level road $= \frac{W \times 5280}{2240} \times \frac{1}{20}$ ft.-tons.

" 4 " " " " $= \frac{W \times 5280}{2240} \times \frac{1}{17}$ "

" 5 " " " " $= \frac{W \times 5280}{2240} \times \frac{1}{14}$ "

"W" denotes the *entire weight carried* and includes the weight of the individual and of all *impedimenta*—*e.g.*, clothes, &c., which weights are to be added to the body-weight.

If there is an ascent, the "rise" must be known, and the additional energy is to be calculated and added to the work done on level-ground.

E.g., supposing the "rise" is 1 in 400 feet, and the entire distance walked = 5280 D feet :

$400 : 5280\ D :: 1 : x = \frac{5280\ D}{400}$ ft. of *vertical* distance $= 13.2\ D\ ft.$

The energy for this additional distance $= 13.2\ D \times \frac{W}{2240}$ foot-tons.

The total energy is the sum of both :

$\frac{W \times 5280 D}{2240} \times$ coefficient of traction $+ \left(13.2\ D \times \frac{W}{2240}\right)$ "

Example.—A soldier 10 stone in weight carries a kit, &c., of 60 lbs. and marches, at the rate of 3 miles per hour, a distance of 7 miles, the ascent being 1 in 500 feet. Calculate the amount of work done in foot-tons.

$W = 10 \times 14 + 60 = 200$ lbs.

$\frac{200 \times 5280 \times 7}{2240} \times \frac{1}{20} = 165$ foot-tons along a *level.*

$500 : (5280 \times 7) :: 1 : x = \frac{5280 \times 7}{500} = 73.92$ ft. of vertical ascent

equal to: $73.92 \times \frac{200}{2240} = 6.6$ foot-tons of energy.

$\therefore$ Total energy $= 165 + 6.6 = 171.6$ foot-tons.

CHAPTER IX.

FOODS.

Milk.

AVERAGE specific gravity at 60° F. = 1031 (water = 1000).

Correction for Temperature.

The sp. gr. of milk falls 1° for each rise of 10° F. above 60° F., and, *vice versâ*, rises 1° for every fall of 10° F. below 60° F.—*i.e.*, inversely as the temperature.

To correct: add or subtract 1° for every difference of 10° F. above or below 60° F.

E.g., Sp. gr. at 40° F. = 1029. 1029 − 2 } = 1027 at 60° F.
„ „ 70° F. = 1026. 1026 + 1 }

For differences of temperature less than 10° F. the same proportion may be taken as approximately correct:

E.g., Sp. gr. at 46° F. = 1030. 60 − 46 = 14° F.
10 : 14 : : 1 : x. = 0.4. 1030 − 0.4 = 1029.6 = sp. gr. at 60° F.

Total Solids.

Weight of 10 c.c. milk + capsule = 44.58 grammes.
„ only = 34.32 „
„ „ = 10.26 „

Weight of total solids + capsule after evaporation.
= 35.67 grammes.
„ „ capsule = 34.32 „
1.35 „

10.26 : 100 : : 1.35 : x = 13.15 per cent. of total solids.

Adam's Process.—METHOD.—10 grms. of milk are absorbed by fat-free bibulous paper, dried and extracted (12 syphonings) with ether in Soxhlet's apparatus. The ether is evaporated off and the residual fat is dried and weighed in a tared flask. The percentage of fat is calculated.

EXAMPLE.—10 grms. milk are treated as above.

Weight of tared flask + fat = 28.867 grammes.
„ „ alone = 28.594 „
„ fat in 10 gms. milk = 0.273 „
„ „ 100 „ = 2.73 „
= 2.73 per cent. of fat.
3.0 − 2.73 = 0.27 per cent. below the standard.

Werner-Schmidt Process.—A known quantity (10 gms.) of milk is placed in a specially graduated tube (Stokes', Fig. 25, or Schmidt's) and boiled with 10 c.c. of strong hydrochloric acid. The casein is destroyed. The contained fat is extracted with ether (added up to the 50 c.c. mark) and estimated after evaporating the ether, and correcting for the residue left in the tube.

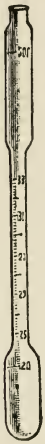

Fig. 25.—Stokes' Tube.

Example.—10 c.c. milk + 10 c.c. strong HCl. Boil and cool. Add ether up to the 50 c.c. mark; shake. Sp. gr. of milk = 1031, 20 c.c. of ether were placed in a weighed dish, evaporated off and the dish dried.

Weight of fatty-residue + dish = 39.016 gms.
„ dish = 38.752 „
Fat in 20 c.c. of ether = 0.264 „

Ether left in tube = 8.6 c.c.
„ pipetted from tube = 20.0 c.c.
} = 28.6 c.c. total amount of ether containing all the fat.

20 : 28.6 : : 0.264 : x = 0.377 gms. fat in 10 c.c. of milk.
= 3.77 „ „ 100 „

Sp. gr. = 1031. ∴ weight of 100 c.c. = $\frac{1031}{10}$ = 103.1 grammes.

∴ 103.1 : 100 : : 3.77 : x = 3.65 per cent. of fat, or 0.65 per cent. above the standard.

If, instead of calculating its weight from its volume and specific gravity, 10 gms. of milk are weighed out:

∴ 0.365 gm. fat in 10 gms. of milk.
= 3.65 per cent. of fat.

Hoppe-Seyler's Process.—Fat, casein and earthy phosphates are precipitated from a solution of milk by adding a little acetic acid and passing a current of CO_2. The precipitate is filtered, and the retained fat extracted with ether in Soxhlet's

apparatus, dried and weighed. The filtrate contains serum-albumen and lactose. The former is separated by boiling and filtering and weighed. The second filtrate contains sugar and salts. The former is estimated by titration with a standard solution of Fehling (10 c.c. = 0.067 gm. lactose).

Ritthausen's Method.

(1) 10 c.c. of milk are diluted with 200 c.c. of distilled water and neutralised with a standard solution of copper sulphate and caustic potash (62.82 gms. $CuSO_4$ per litre; 1 c.c. = 0.1 gm. CuO). The precipitate, consisting of fat and albuminate of copper, is collected on a filter-paper of known weight by suction.

The fat is extracted by Soxhlet's method and weighed.

(2) The albumen is calculated by the difference in weight of the filter-paper before and after the extraction of the fat, deducting the weight of copper oxide in the precipitate.

(3) The filtrate contains lactose, which is calculated by titrating with a standard solution of Fehling (10 c.c. = 0.067 gm. lactose).

EXAMPLE:

1. Weight of fat-flask + extracted fat = 19.957 gms.
   „ „ „ alone = 19.635 „
   difference = 0.322 gm. fat in 100 c.c. milk.
   = 3.22 per cent. of fat.

2. Weight of filter-paper (in test-tube) + „ albumen + „ copper oxide = 17.251 gms.
   „ „ filter-paper (in test-tube) only = 16.730 „
   difference = 0.521 gm. albumen and copper oxide in 10 c.c. milk.

   0.521 − 0.1 = 0.421 gm. albumen.
   = 4.21 per cent. of albumen.

3. Filtrate from (1) made up to 300 c.c.

44.8 c.c. were required in titrating 10 c.c. of Fehling's solution (= 0.067 gm. lactose).

∴ 44.8 : 300 :: 0.067 : x = 0.44 gm. lactose in 10 c.c. of milk.
= 4.4 per cent. of lactose.

Richmond's Formula.—To calculate the percentage of fat, total solids and sp. gr. being known.

Percentage of fat = (Total solids × 0.859) − ("G" × 0.2186).

"G" = last two units of the specific gravity and any decimal; or, = specific gravity − 1000.

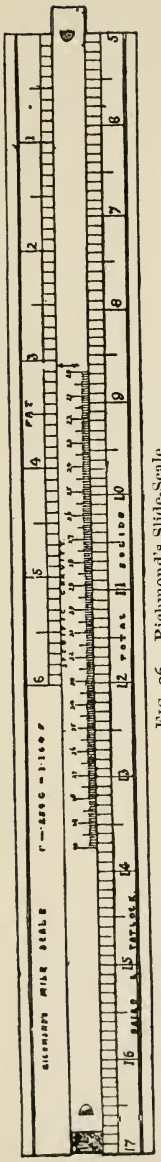

Fig. 26.—Richmond's Slide-Scale.

E.g., total solids = 10.8. Sp. gr. at 60° F. = 1031.5. "G" = 31.5.

Percent. of fat = $(10.8 \times 0.859) - (31.5 \times 0.2186)$.
$= 9.2772 - 6.8859$.
$= 2.39$ per cent. of fat.

By the above formula the third term can be calculated if the other two are known:

E.g., percentage of fat = 3. Sp. gr. = 1032.

To find total solids:

$3 = 0.859x. - (32 \times 0.2186)$.

$3 + 6.9952 = 0.859x$. $x = 11.63$ per cent. of total solids.

A more recent formula for calculating total solids is:

Total solids = 1.2 × percentage of fat + 0.14 + 0 25 G.

The above example would give:

$1.2 \times 3 + 0.14 + 0.25 \times 32 = 11.74$ per cent. of total solids.

Richmond's Slide-Scale (Fig. 26).—If two terms are known the third can be found. The sliding-scale in the middle indicates specific gravity; the upper one, fat; and the lower, total solids.

If specific gravity and fat per cent. are known, place the arrow-head (of the sliding-scale) under the figure denoting the per cent. of fat, and the specific gravity figure will coincide with that for total solids.

If specific gravity and total solids per cent. are known, let these figures coincide on the scale, and the arrow-head will indicate the percentage of fat. The scale is used in conjunction with other methods (*e.g.*, Leffman Beam's process for the estimation of fat) as an approximate check on the results.

Milk Standards.—Fat = 3 per cent.
Solids not fat = 8.5 per cent.

To Estimate the Amount of Fat abstracted, the percentage of fat present being known:

E.g., sample contains 2.18 per cent. fat. 3.0 − 2.18 = 0.82 per cent. removed.

Or:

$3 : 2.18 : : 100 : x = \frac{218}{3} = 72.7$ per cent. of the original fat remains, and $100 - 72.7 = 27.3$ per cent. has been abstracted.

To Estimate the Quantity of Water added. (1) *From non-fatty solids.*—This is done by calculating the amount of "solids not fat" in the sample, as they are less variable in quantity than the fat in a genuine sample of milk.

E.g., sample contains 7.25 per cent. of total solids.

$8.5 : 7.25 : : 100 : x = \frac{725}{8.5} = 85.3$ per cent. of pure milk.

$100 - 85.3 = 14.7$ per cent. of water added.

(2) *From the ash* (which also varies little in a genuine sample).

E.g., ash after ignition of sample = 0.6 per cent.

$7 : 6 : : 100 : x = \frac{600}{7} = 85.7$

$100 - 85.7 = 14.3$ per cent. of water added.

Butter.

Moisture.—Should not exceed 16 per cent.

EXAMPLE.—Weight of dried capsule = 21.53 grammes.
„ butter taken = 1.00 „
22.530
Weight after evaporating, drying and cooling = 22.417 „
0.113 „
= 11.3 per cent. moisture.

Soluble and Insoluble (Volatile and Fixed) Acids.

METHOD.—The melted fat is saponified in methylated spirit with caustic potash, and the volatile acids, set free by dilute sulphuric acid, are distilled over into $\frac{N}{10}$ NaHO, and estimated by titration with $\frac{N}{10}$ oxalic acid.

The fixed acids, after the addition of sulphuric acid, are evaporated, dried and weighed (not distilled over).

EXAMPLE.—**Volatile Acids.**

2.5 grammes butter-fat + 5 grammes caustic potash + 50 c.c. methylated spirit (Saponified). After evaporating off the spirit

the residue is dissolved in distilled water, mixed with dilute sulphuric acid and distilled.

150 c.c. distilled off into 20 c.c. $\frac{N}{10}$ NaHO.

Titrated with $\frac{N}{10}$ oxalic acid (1 c.c. = 8.8 mgr. butyric acid).

On trial 20 c.c. $\frac{N}{10}$ NaHO = 18 c.c. $\frac{N}{10}$ oxalic acid.

Distillate + 20 c.c. $\frac{N}{10}$ NaHO = 2.0 c.c. $\frac{N}{10}$,,

$\therefore$ 18 − 2 = 16 c.c. $\frac{N}{10}$ oxalic acid not used up.

16 × 8.8 = 140 mgrs. butyric acid in 2.5 ($\frac{1}{40}$ of 100) gms. butter.

140 × 40 = 5600 mgrs. in 100 grammes butter = 5.6 per cent. of butyric acid.

Fixed Acids: 5 grammes butter-fat saponified similarly as above and treated with dilute sulphuric acid, evaporated, dried and weighed in capsule of known weight:

Weight of capsule + fatty acids = 57.774 grammes.

,, ,, alone = 53.154 ,,

Difference = 4.620 ,, fixed acids in 5 grammes butter-fat.

= 92.4 per cent.

Specific Gravity of Butter-fat.

(1) By a specific gravity bottle at 35° C. or at 100° F.

(2) By Westphal's balance (p. 24).

(1) $\frac{\text{Weight of melted butter-fat at 100° F.}}{\text{Weight of distilled water at 100° F.}}$ (water = 1000).

Example.—Weight of empty specific gravity bottle = 11.85 grammes.

Weight of bottle + distilled water at 100° F. = 35.6 grammes.

,, ,, + melted fat at 100° F. = 33.415 ,,

,, melted fat at 100° F. = 33.415 − 11.85 = 21.565 grammes.

,, distilled water at 100° F. = 35.6 − 11.85 = 23.75 grammes.

Specific gravity of fat at 100° F. $= \frac{21.565}{23.75} = 0.908$

= 908 (water = 1000)

Lowest specific gravity of pure butter-fat = 910

Highest ,, ,, foreign fat = 904

Difference = 6

= 100 per cent. of adulteration.

In the example, difference = 910 − 908 = 2.
6 : 2 : : 100 : x. = 33.3 per cent. of adulteration with other fat.

Estimation of Albumenoids in Meat, Cereals, &c.

Kjeldahl's Method.—Organic matter is powdered, and boiled with concentrated sulphuric acid till colourless. Potassium permanganate is added to oxidise it into ammonium sulphate. On cooling, distilled water and caustic soda solution are added, and the ammonia is distilled into $\frac{N}{10}$ hydrochloric or oxalic acid and titrated with $\frac{N}{10}$ alkaline solution, and the nitrogen determined.

Example.—0.2 gramme oatmeal + 10 c.c. strong sulphuric acid digested till straw-coloured + $KMnO_4$ and boiled till colourless; + 250 c.c. 10 per cent. NaHO solution + 100 c.c. distilled water, 150 c.c. distilled into 10 c.c. $\frac{N}{10}$ oxalic acid, and titrated with $\frac{N}{10}$ NaHO.

On titrating, 10.2 c.c. $\frac{N}{10}$ NaHO = 10 c.c. $\frac{N}{10}$ oxalic acid.

10 c.c. of $\frac{N}{10}$ oxalic acid + distillate from flask = 6.7 c.c. $\frac{N}{10}$ NaHO.

10.2 : 6.7 : 10 : x. = 6.6 c.c. $\frac{N}{10}$ oxalic acid.

10 − 6.6 = 3.4 c.c. $\frac{N}{10}$ oxalic acid neutralised by NH_3 distilled over.

1 c.c. $\frac{N}{10}$ oxalic acid = 1.7 mgr. NH_3.

$3.4 \times 1.7 = 5.8$,,

$5.8 \times \frac{14}{17} = 4.8$ mgr. nitrogen.

$4.8 \times 6.25 = 30$ mgr. albumen in 0.2 gm. of oatmeal.
= 15 mgr. in 0.1 gramme.
= 15 per cent. albumen.

Alcohol.

Absolute alcohol.	Specific gravity at 60° F. = 0.79.
,, ,,	+ 16 per cent. water = rectified spirit.
,, ,,	+ 42.95 per cent. water = proof ,,

Proof-spirit is taken as the standard. Its specific gravity at 60° F. = 0.92. A spirit containing less alcohol than proof-spirit is "underproof"; if containing more, "overproof."

Proof-spirit = 57.05 per cent. absolute alcohol, volume in volume, in distilled water.

„ = 49.25 per cent. absolute alcohol, weight in weight, in distilled water.

„ = 42.46 per cent. absolute alcohol, weight in volume, in distilled water.

To calculate the ratio of alcohol to proof-spirit as:

(1) volume in volume : 57.05 : 1 : : 100 : x. = 1.753.

(2) weight in weight = 49.25 : 1 : : 100 : x. = 2.03.

(3) „ volume = 42.46 : 1 : : 100 : x. = 2.35.

To calculate degrees "over-" and "under-proof":

(1) A sample of whisky is 25° under-proof:

1.753 : 1 : : (100 − 25) : x. = 42.8 per cent. absolute alcohol, *volume in volume.*

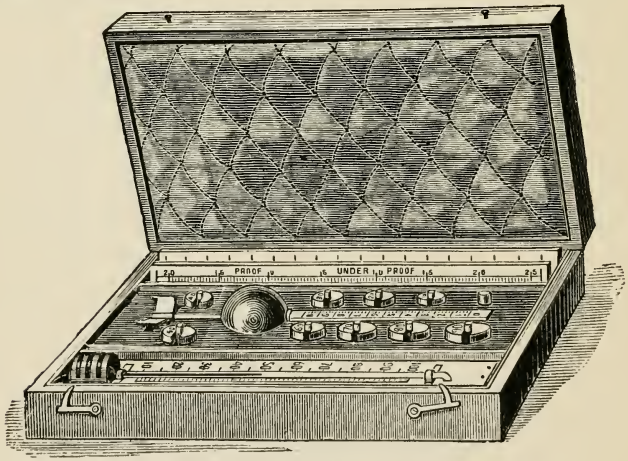

Fig. 27.—Sike's Hydrometer.

(2) Brandy 15° over-proof:

2.03 : 1 : : (100 + 15) : x. = 56.6 per cent. absolute alcohol as *weight in weight.*

(3) A sample of gin 35° under-proof:

2.35 : 1 : : (100 - 35) : x. = 27.6 per cent. absolute alcohol as *weight in volume.*

(4) A spirit contains 28 per cent. of alcohol, volume in volume: 57.05 : 28 : : 100 : x. $= 49.08$. $100 - 49.08 = 50.92$ under-proof.

In Great Britain Sike's Hydrometer (Fig. 27) is used in distilleries and breweries. It is supplied with Tables giving the percentage of alcohol corresponding to the readings. The instrument floats at zero in strong spirit, specific gravity = 0.825, and the heaviest disc will make it float at zero in distilled water —giving a range of 500° between these.

The amount of alcohol in beer is determined as follows:

Mulder's Method.—Determine the specific gravity of the beer at 15.5° C. or 60 F. Take 300 c.c. and distil off 200 c.c.

Make up the distillate to 300 with distilled water, and take the specific gravity of the mixture, referring to the Tables for the percentage of alcohol indicated by the reading.

To verify this result: (1) make up the residue in the distillation flask (100 c.c.) to 300 c.c. and take the specific gravity; (2) subtract from this the specific gravity of the original beer; finally subtract this result from 1000. This figure ought to correspond with the specific gravity of the distillate (200 c.c.) when made up to 300 c.c.

EXAMPLE.—Specific gravity of original sample of beer = "1015."

300 c.c. are placed in a distillation-flask; 200 c.c. are distilled off and are made up to 300 c.c. with distilled water.

Specific gravity of distillate (made up to 300 c.c.) = "995."

By Tables the reading "995" = 3.35 per cent. alcohol.

Specific gravity of residue in flask (100 c.c.) made up to 300 c.c. = 1020.

$\therefore$ $1020 - 1015 = 5$. $1000 - 5 = 995$.

Acidity of Beer. METHOD.—10 c.c. are diluted with distilled water and titrated with $\frac{N}{10}$ NaHO. The result is expressed in terms of *lactic* acid. $\frac{N}{10}$ oxalic acid is used for testing the $\frac{N}{10}$ NaHO. Phenol-phthalein is the "indicator."

Lactic acid = $C_3H_6O_3 = 90$. $\frac{N}{10} = 9$ grammes per litre.

1 c.c. = 9 mgr.

EXAMPLE.—10 c.c. beer are treated as above.

On titration = 2.1 c.c. $\frac{N}{10}$ NaHO.

On testing $\frac{N}{10}$ NaHO. 10.3 c.c. = 10 c.c. $\frac{N}{10}$ oxalic acid.

$$\therefore\ 10.3 : 2.1 : : 10 : x. = 2.04 \text{ c.c. } \frac{N}{10} \text{ oxalic acid.}$$

but $2.04 \times 9 = 18.36$ mgr. *lactic* acid in 10 c.c. beer.
$= 0.1836$ per cent. lactic acid.

The acidity of wine is expressed as tartaric acid. The method of calculation is similar.

CHAPTER X.

LOGARITHMS AND LOGARITHMIC TABLES.

The logarithm * of a number is the "index" of the power to which a constant number, called *the base*, must be raised to equal the number of which the "index" is the logarithm.

If $a^n = x$, n is the logarithm of the number x to the base a.

The logarithm of 64 to the *base* 4 is 3, because $4^3 = 64$; the logarithm of 64 to the base 8 is 2 : $8^2 = 64$.

It is expressed thus: $\text{Log}_a\, x = n$; $\text{Log}_4\, 64 = 3$; $\text{Log}_8\, 64 = 2$.

The "base" is placed between the letters "Log" or "L." and the number of which the logarithm is given.

In the common system of Logarithms the base employed is 10, and the power to which 10 is raised to produce any number is the logarithm of that number. As this base is in general use for all calculations, it is not written down, so that if no base is indicated it is understood to be 10. In the Napierian system the base is 12, indicated by *e*, but this method is not in use.

Log 269 = 2.4297523, means therefore that the base 10 raised to the power 2.4297523 is equal to 269.

10 being taken as the base, the logarithm of 10 (*i.e.* of the base itself) = 1 as $10^1 = 10$, and log 10 = 1 ; therefore $10^2 = 100$, and log 100 = 2 ; and log $10^4 = 10{,}000$, and log 10,000 = 4, &c.

If, instead of multiplying 10 by itself, it is divided by itself : $\frac{10}{10} = 1$, indicated thus : $10^0 = 1$; therefore log 1 = 0.

$$\frac{10}{10 \times 10} = \frac{1}{10} = 0.1 = 10^{-1} \quad \log 0.1 = -1.$$

$$\text{Similarly : } \frac{1}{10{,}000} = 0.0001 = 10^{-4} \quad \log 0.0001 = -4$$

The logarithm of 10 being 1, that of all numbers less than 1 consists entirely of decimals, there being no whole number.

The integral part of a logarithm (the whole number or numbers to the left of the decimal point) is known as the

* The number corresponding to a given logarithm is termed its "anti-logarithm."

Characteristic, and the decimal part (figures to the right of the decimal point) as the Mantissa.

E.g. log 4176 = 3.6207605; the Characteristic is 3 and the Mantissa .6207605. The latter usually contains seven figures.

Numbers consisting of *one* whole number and any decimals have zero as a Characteristic.

E.g. log 2.83 = 0.4517864.
log 1.386 = 0.1417632

The Characteristic in all cases is omitted from Logarithmic Tables and must be prefixed by the calculator himself, as can easily be done on inspection by the following Rules:

1. *If the logarithm to be found is that of a number containing* one or more integers:

The Characteristic is one less than the number of integral figures in the number.

E.g. log 864 = 2.9365137.
log 86.4 = 1.9365137.
log 8.64 = 0.9365137.

It is to be observed that so long as the figures in the number remain the same the *Mantissa also remains the same;* the Characteristic alone changes, according to the position of the decimal point, *i.e.* as the number of integers.

2. If the logarithm to be found is that of a number containing decimals only and no integers, the Characteristic is the same as the place to the right of the decimal point which the first significant figure (not a zero) of the number occupies. The Characteristic is *negative*, and to distinguish it from a positive Characteristic has a negative sign or "bar" placed *above* it—not in front.

E.g. log 0.854 = $\bar{1}$.9314579, 8 being the *first* significant figure after the decimal, $\bar{1}$ is the Characteristic with the negative "bar" over it. (It follows that a positive Characteristic indicates a whole number.)

Log 0.0854 = $\bar{2}$.9314579, where 8 is in the second place—zero not counting as a significant digit. Similarly log 0.00023 = $\bar{4}$.3617278.

The Characteristic of a logarithm may therefore be positive (+) or negative (−), but the Mantissa is *never a negative quantity*, it is *always positive.* (*Vide* p. 127.)

Tables of Logarithms.

In these only the Mantissa of the numbers (indicated in the first column on the left of each page under the heading "No.") is

given. As already explained, the Characteristic is prefixed on inspection.

The descriptions here furnished are applicable to the *Mathematical Tables* published by Messrs. W. & R. Chambers, Ltd., which are in universal use; but the methods are, of course, applicable to all similarly-constructed Tables.

In these the Mantissa of each Number is in a line with it, and *vice versâ*. The first three or four figures following the decimal point are in numbers after 999 in the first column to the right of the number and are to be prefixed to *all* the groups of *four* figures (under the columns headed "0," "1," "2," "3," "4." . . . "9"), whether these groups are on the same line with them or on at *lower* level but above the next group of initial figures.

The numbers 1 to 999 are each given separately.

Thus:

No.	Log.	No.	Log.
751	8756399	951	9781805
		...	...
752	8762178	996	9982593

So that log 752 = 2.8762178.

log 0.951 = $\bar{1}$.9781805.

Example.—In the Tables we find:

No.		0	1	2	3	&c.
1067	028	1644	2051	2458	2865	&c.
*	*	*	*	*		
69		9777	$\overline{0183}$	$\overline{0590}$	$\overline{0996}$	&c.
70	029	3838	4244	4649	5055	&c.

That is, log 1067 = 3.0281644

,, 10670 = 4. ,,

,, 10671 = 4.0282051

,, 10673 = 4.0282865

,, 1069 = 3.0289777

but log 10691 = 4.0290183

log 1070 = 3.0293838, and similarly the others.

Note that the first three figures, *e.g.* "028," are carried on for all the columns till another set of three, *e.g.* "029," is met with, the exception being where there is a line drawn over the last four figures of the Mantissa, *e.g.* $\overline{0183}$, $\overline{0966}$, &c., as above. In these cases the three first figures of the next Mantissa (below) must be prefixed, it being a matter of convenience to denote the alteration in this way rather than to have a broken line of figures in the Tables, and also to economise space.

After the number 99999, the first four figures of the Mantissa are supplied, but the method of working is the same.

Note the logarithm of 1, 10, 100, 1000, &c., is represented by 0 ; that is, there is *no Mantissa*, but only a Characteristic, which, as already explained, is to be 0, 1, 2, 3, &c., and is put down on inspection, as before.

To Find the Logarithm of a given Number.—1. For numbers containing less than four figures: the Mantissa is read off at once, and lies by the side of the number as already indicated.

2. For numbers of *five figures*: the Mantissa is found under "0"—the first four decimals are a little to the left of the zero in the first column of figures, and the rest directly under the figures 0 . . . . 9 at the top of the page.

E.g. log 90626 = .957 (traced upwards opposite "9058"),
and 2528 (the next four decimals under "6"),
entire *Mantissa* = .9572528
,, *logarithm* = 4.9572528
but log 0.00906 is found under "906," and is equal to $\bar{3}$.9571282.

For numbers of six figures. The Mantissa is found for the first five figures of the number in the same way as before. To obtain the *sixth* figure subtract the Mantissa of the first five figures from that of the *next higher* number (*i.e.* from the *next higher Mantissa*). The difference will coincide with the figures at the top of the adjacent "column of proportional parts" under the heading "Diff" (at the extreme right of every page). Find in this column (numbered 1 to 9) the sixth figure of the given number, and opposite to it will be found the figures which must be added to the last digits of the Mantissa first found (*the Mantissa of lower value*).

Example.—To find log 268354.

The logarithm of the first five figures of this number is easily found in the usual way opposite to the figures 2683, and under 5, and as the sixth figure 4 cannot be read off, the Mantissa corresponding to the first five figures must be subtracted from the Mantissa of 26836—*i.e.*, the first figures to the right of the last

log 26836 = 4.428717*8*
log 26835 = 4.428701*6*
Difference = 162

This difference corresponds to the figure "162" at the top of the column under "Diff." Opposite "4" in this column, which is the required sixth figure of the given number, is found "65,"

which must be added to the last digits of the lower Mantissa first found, thus: log 26835 = 4.4287016
65
„ 268354 = 5.4287081 which is the required log.

(NOTE.—The sixth figure of the numbers from 100001 to 10800 inclusive can be ascertained directly from the Tables.)

To Find the Logarithm of a Number containing Seven Figures.

EXAMPLE.—Find log 5067958.

log 50680 = 4.7048366
log 50679 = 4.7048280

Difference = 86 coinciding with 86 in the "Diff." column.

Opposite "5" in this column (which is the sixth figure in the given Number) is "43," and opposite 8 (the seventh figure of the Number) is "69."

Therefore: log 50679 = 4.7048280 (the lower Mantissa)
43
log 506795 = 5.7048323
69
log 5067958 = 6.7048329ø

Note 69 is placed, for the seventh figure, one decimal place farther to the right. 69 may be taken as 7.0, and adding 7 to the last figure, 3, of the Mantissa we have log 5067958 = 6.7048330.

EXAMPLE.—Find log 317.1626

log 317.17 = 2.5012921
log 317.16 = 2.5012784

Difference = 137

Diff.	
137	
2	27
6	82

log 317.16 = 2.5012784
27
log 317.162 = 2.5012811
82
log 317.1626 = 2.5012819ø

To Find the Logarithm of a Number of Eight Figures.

EXAMPLE.—Find log 23453487

log 23454 = 4.3702169
log 23453 = 4.3701984

Difference = 185

	Diff.
	185
4	74
8	148
7	130

log 23453 = 4.3701984

4	74
8	148
7	130

log 23453487 = 7.3702074[10]

To Work with negative Characteristics (denoting that the numbers of which they are the logarithms are decimals) the ordinary Algebraical methods of addition and subtraction are used, as in all logarithmic calculations.

EXAMPLES.—

Addition:	5.2657845	3.0624316	$\bar{2}.3461573$
	$\bar{2}.4983106$	$\bar{7}.2713769$	1.8692317
	3.7640951	$\bar{4}.3338085$	0.2153890

(1 carried over to 1 $= 2 + \bar{2} = 0$)

Subtraction:

[The sign of the negative Characteristic which is to be subtracted is changed to + and the two Characteristics are added as in Algebra; the Mantissa is subtracted in the ordinary way, being positive.

E.g., $3a + 2b - (a - b) = 3a + 2b - a + b$ (the two negatives before b changing to +) $= 2a + 3b$.

EXAMPLES.—

Subtraction.	4.6290016	$\bar{5}.0986437$	$\bar{4}.5641925$
(*minus* $\bar{5} = 5$)	$\bar{5}.3751147$	$\bar{7}.4352071$	6.6580496
	9.2538869	1.6634366	$\bar{11}.9061429$

(1 carried over is subtracted
$\therefore \bar{5} - 1 = \bar{6}$, and $\bar{7} + \bar{6} = 1$.)

Multiplication. $\bar{2}.7460423$

$\times \quad 5$

$\bar{7}.7302115$ ($\bar{2} \times 5 = \overline{10} + 3$ carried over $= 7$).

Division. As the Mantissa must remain positive, the Characteristic must be completely divisible by the divisor, and nothing is to be carried into the Mantissa. If the Characteristic is divisible as it stands, the quotient is written down in the usual way with the negative bar; if it is not divisible, a negative number is to be added to it to make it so, and to the Mantissa is prefixed a positive integer of equal value, so that the $-$ and $+$ correct each other and leave the value of the logarithm unaffected, and the division is carried out as usual.

EXAMPLE.—$\log \bar{8}.1626540 \div 4 = \bar{2}.0406635$

„ $\quad \div 7 = (\bar{8} + \bar{6}) + 6.1626540 \div 7$

$= \log \bar{2}.8803791.$

To Find the Number from the given Logarithm.—The method is the reverse of the one for finding the logarithm of a number. Look up the Mantissa under the appropriate columns in the Tables—*i.e.*, under the cyphers 0 to 9 (at the top of the page). If the decimal part is found exactly, the corresponding number is to be read off in the first column (under No.) and the decimal point placed as indicated by the Characteristic of the given logarithm. These integers will be numerically *one more* than the Characteristic.

E.g., ".7291648" found under "0" corresponds with the figures 5360 (under No.), but the position of the decimal point and the value of the figures of the number can only be ascertained from the Characteristic of the logarithm.

$\therefore \quad 0.7291648 = 5.360 \ (5.36)$

$1.7291648 = 53.6$

$5.7291648 = 536000.$

If the given Mantissa is not found in the Tables, take out the *next lower Mantissa* and subtract it from the Mantissa of the given logarithm. The difference will be found exactly or approximately in the right-hand column of figures of the Table of Proportional Parts (under "Diff."), and the figure opposite to it is the sixth figure of the required number.

"If the difference is not exactly found among the proportional parts, take the next lower part, and the figure opposite to it is the sixth figure of the number.

"Subtract this part from the given difference, annex a cypher to the remainder, consider it as a new proportional part, and find

the corresponding figure as before. It will be the seventh figure of the number."

Example.—To find the number corresponding to the given logarithm 5.9173597.

The given Mantissa is not exactly stated in the Tables, therefore taking the *next lower* and subtracting:

5·9173597		
5·9173584 corresponding to the number 826720		
Diff. = 13	"Diff."	
2 10	" " "	02 (6th figure)
10	6 31	006 (7th figure)
30 (cypher annexed, the nearest in the Table of Proportional Parts = 31)		8267226, which is the required number.

Logarithms are valueless for the Addition and Subtraction of numbers. They are serviceable only for performing multiplication, division, raising to any power, and for extracting any root. The results in most cases are a close approximation, and not absolutely correct unless the numbers are represented by a perfect value in the logarithm.

In all cases the logarithm of the number must be known.
Multiplication of numbers = addition of their logarithms.
Division " = subtraction " "

Raising to any power = multiplication of the logarithm of the number by the figure denoting the power to which it is to be raised.

Extraction of any root = division of the logarithm of the given number by the figure denoting the desired root.

Thus: $X \times Y = \log X + \log Y$ = addition of logarithms.

$$\frac{X}{Y} = \log X - \log Y = \text{subtraction} \quad ,,$$

$X^n = n$ times $\log X$ = multiplication of the logarithm.

$$\sqrt[n]{X} = \frac{\log X}{n} \quad = \text{division} \quad ,, \quad ,,$$

Processes are thus shortened considerably by the aid of Tables: the logarithms of the numbers are easily found, and *vice versâ* the logarithms being known, the numbers are ascertained.

It is to be noted that logarithms *themselves* are not multiplied or divided by each other.

EXAMPLES.—*Multiplication of numbers* 102718×91627.

$$\log 102718 = 5.01164655$$
$$\log 91627 = 4.96202350$$
$$9.97367005$$

The Characteristic shows there are 10 integers in the number.

As the above Mantissa is not found in the Tables, the *next lower* is taken out and subtracted from it.

$$9.9736700$$
$$9.9736681 = \log \text{ of } 9411700000.$$

Diff.		
46	19	
4 18	18	$\therefore$ 6th figure = 4.
2 9	10	7th ,, = 2.

$\therefore$ 9411742000 = Antilogarithm.

Division of Numbers.

$$\frac{67564}{83619} = \log 67564 - \log 83619.$$

$\therefore$ 4.8297154
4.9223050

$\bar{1}.9074104 = \log 0.808$, which is the required decimal.

Raising to a Power (Involution).

To find the value of $(12.6)^6$

$$= 6 \times \log 12.6$$
$$= 6 \times 1.1003705 = 6.6022230$$

which is the logarithm of the number 4001500.

Extraction of the Root (Evolution).

To find the value of $\sqrt[4]{58726}$

$$= \frac{\log 58726}{10 \times 4} = \frac{4.7688304}{10 \times 4} = 0.11922076$$

corresponding to the number 1.3159.

CHAPTER XI.

POPULATION.

Estimation of Population by Logarithms.—The increase is in Geometrical Progression.

Let P = Population in any given year.
r = factor of annual increase.
$P \times r$ = increase in one year.
$P \times r^2$ = „ „ two years.
$P \times r^n$ = „ „ n „

The rate of increase or decrease is calculated from the data of the two previous Censuses.

The *assumption* is that either has *continued at the same rate* since the last Census as between the last and the previous Census.

Registrar-General's Method of Estimating a Population.

Log Census Population + log Quarterly increase + n times log. Annual increase = log Population at the middle of the n^{th} year since the last Census (*i.e.*, the n^{th} post-censal year).

Formula.—*By Geometrical Progression:*

If y = population by the last Census.
x = „ „ „ previous „ (10 years before).

Rate of Decennial increase $= \frac{y}{x} = \log y - \log x$.

„ Annual „ $= \sqrt[10]{\frac{y}{x}} = \frac{\log y - \log x}{10}$.

„ Quarterly „ $= \frac{1}{4}$ of $\frac{\log y - \log x}{10}$.

$= \frac{\log y - \log x}{4 \times 10}$.

The Census population for the middle of the Census-year is, therefore, the *actual* population on March 31 of that year *plus* or *minus* the hypothetical increase or decrease calculated (with

logarithms) by Geometrical Progression from April 1 to June 30 inclusive. It is not the real mid-year population, but only an approximate one.

Increasing Population.

EXAMPLE.—1881. Population = 462303.
1891. „ = 505368.

Estimate the Population in 1898 (mid-year).

log 462310 = 5.6649333 } Diff.
log 462300 = 5.6649239 } 94
3 28

log 462303 = 5.6649267 = log Population 1881.

log 505370 = 5.7036095 } Diff.
log 505360 = 5.7036009 } 86
8 69

log 505368 = 5.7036078 = log Population 1891.
5.6649267 = „ „ 1881.

Difference = 0.0386811 = „ Decennial increase.
$\frac{1}{10}$ = 0.0038681 = „ Annual „
$\frac{1}{4}$ = 0.0009670 = „ Quarterly „

log 0.0038681 × 7 = 0.0270767 = „ 1892–8 „
5.7036078 = „ Population 1891.
0.0009670 = „ Quarterly increase.

5.7316515 = „ Population 1898.

539070 = 5.7316452

		Diff.
539077	63	7 57
7	57	
539077·7	60	

or 539078 = population for 1898.

EXAMPLE.—Population 1891 = 531247
„ 1901 = 985476

To find the mid-year Population for 1907.

log 531250 = 5.7252989 } Diff.
log 531240 = 5.7252908 } 81
7 57

log 531247 = 5.7252965 = log Population 1891.

log 985480 = 5·9936478 } Diff.
log 985470 = 5 9936434 } 44
6 26 } 6 26

log 985476 = 5.9936460 = log Population 1901.
5.7252965 = ,, ,, 1891.
Difference 0.2683495 = ,, Decennial increase.
$\frac{1}{10}$ = 0.0268349 = ,, Annual ,,
$\frac{1}{4}$ = 0.0067087 = ,, Quarterly ,,
log 0.0268349 × 6 = 0.1610094 = ,, 1902–7 ,,
5.9936460 = ,, Population 1891.
0.0067087 = ,, Quarterly increase.
6.1613641 = ,, Population 1907.

1449900 = 6.1613380
8 261 Diff.
1 240 8 240
1 30
21

1449981 = Population for 1907.

Decreasing Population.

Example.—A population of 552508 in 1891 was found to have decreased in 1901 to 517980.

To calculate the population in 1906 on the hypothesis that it will decrease at the same rate:

log 552510 = 5·7423401 } Diff.
log 552500 = 5·7423323 } 78
8 62 } 8 62

log 552508 = 5.7423385 = log Population 1891.
log 517980 = 5.7143130 = ,, ,, 1901.
Difference 0.0280255 = ,, Decennial decrease.
$\frac{1}{10}$ = 0.0028025 = ,, Annual ,,
$\frac{1}{4}$ = 0.0007006 = ,, Quarterly ,,
= 0.0147131 log Total decrease to middle of 1906.
log 0.0028025 × 5 = 0.0140125 = log Decrease from 1901–6.

5.7143130
Subtracting: 0.0147131
5.6995999 = log Population for 1906.
5.6995949 = ,, 500720

Diff.
50 5 5 44
44 7 7 61
60 500725·7
or 500726 = Population for 1906.

Estimation of a Population by Arithmetical Progression.

EXAMPLE.—1901. Population = 50742
1891. ,, = 47256
To estimate the Popul. in 1908:

3486 = Decennial increase.
$\frac{1}{10}$ = 348.6 = Annual ,,
$\frac{1}{4}$ = 87.15 = Quarterly ,,
348.6 × 7 = 2440.20 = 1902–08 ,,

1901 Population + Quarterly Increase + 7 times Annual Increase
= 53269.35 = Mid-year Population for 1908.

Working the above by Geometrical Progression and by Logarithms:

log 50742 = 4.7053676 log Population of 1901.
log 47256 = 4.6744570 ,, ,, ,, 1891.

0.0309106 = ,, Decennial increase.
$\frac{1}{10}$ = 0.0030910 = ,, Annual ,,

$\frac{1}{4}$ = 0.0007727 = ,, Quarterly ,,
log Annual Increase × 7 = 0.0216370 = ,, 1902–8 ,,
4.7053676 = ,, Population of 1901.

Adding the last three: 4.7277773 = ,, ,, ,, 1908.
Corresponding Number = 53429.00 = Population of 1908
53269.35 ,, as above by A.P.
Disparity = 159.65

(This is a small difference, because the increase is a slow one in a comparatively small Population. In such a case A.P. is applicable with fairly accurate results. It is inadmissible for a large Population.)

Estimation of Population from the Birth-rate (per 1000 living).—The method suggested by Dr. Newsholme is useful for checking the estimate of a "present" population. *It is assumed* that the birth-rate remains for some years the same as it was when the last Census was taken.

EXAMPLE.—Birth-rate (per 1000 living) 1892–1901 inclusive = 30.2 Births during 1902 = 4678

30.2 : 4678 : : 1000 : x = 154900.

$$\text{Weekly population} = \frac{\text{Mean Annual Population}}{52.177}$$

$$\text{Daily ,,} = \frac{\text{Mean Annual Population}}{365.24}$$

Marriage-rate.—It is calculated by Simple Proportion on the actual population, and is expressed per 1000 living at all ages.

E.g. Population in 1899 = 18426.
Marriages ,, ,, = 284.
18426 : 1000 : : 284 : x = 15.4 per 1000 living.

Birth-rate.*—General Formula:
Mean Annual Population : 1000 : : Annual Births : x.
Crude Birth-rate : per 1000 of estimated (mid year) population *at all ages.*

Annual Birth-rate : Mid-year population = 29542.
Births *registered* during the year = 865.
29542 : 1000 : : 865 : x = 29.2 per 1000 living.

Quarterly Birth-rate : Taking the same population.
Births registered during quarter in question = 186.

(1) 29542 : 1000 : : 186 : x = 6.3
and (2) 6.3 × 4 = 25.2 per 1000 = *Quarterly* Birth-rate.

[Note.—The result denotes what the *Quarterly rate* would be per annum if it went on at the same rate for one whole year per 1000 living.]

Weekly Birth-rate : *E.g.* Population = 28530.
Births during week in question = 19.
Weeks in the year = 52.177.
(1) 28530 : 1000 : : 19 : x = 0.67.
(2) 0.67 × 52.177 = 34.96 per 1000 living.

The Birth-rate is preferably calculated on the female population *at the child-bearing age*, per 1000 married and per 1000 unmarried.

Death-rates.—The *crude* (general or gross) *death-rate* is that of the mid-year population (at all ages) per 1000 living.

E.g. Population = 18500. Deaths during the year = 206.
Annual Death-rate : 18500 : 1000 : 206 : x = 11.1 per 1000.
For the same population, deaths during a particular week = 7.
Annual Death-rate *for that week:*

(1) 18500 : 1000 : : 7 : x = 0.38.
(2) 0.38 × 52.177 = 19.8 per 1000.

A Weekly Death-rate estimates the number who would die *per annum* per 1000 living if the death-rate of that week continued at the same rate throughout one year. A Quarterly Death-rate is estimated in a similar way.

* Birth-rate, Death-rate at all ages, and the Net Death-rate (columns 4, 8, and 13 of the M.O.H.'s Vital Statistics Tables) are calculated per 1000 of estimated population.

"Corrected Death-rate" of the Registrar-General.

The correction is made by multiplying the local Recorded Death-rate of the Town (or crude death-rate) by the factor supplied to it annually by the Registrar-General. It neutralises errors in death-rates caused by the disparity of age- and sex-distribution, and raises or lowers the local crude death-rate to what it would be if the age- and sex-distribution of the town were the same as for England and Wales generally. The same method is carried out throughout Great Britain.

To obtain the **Registrar-General's "Factor."**

1. A local *standard death-rate* is calculated for each town. The local distribution of ages and sexes is obtained from the last Census. To this *local population* is applied the annual Death-rate of England and Wales for the previous 10 years (*i.e.*, as if the people had died at the same annual rate as for England and Wales during the last 10-year interval, and *not at the local death-rate*).

2. The annual recorded death-rate (at all ages) for England and Wales for the previous Decennium divided by this local standard death-rate gives the "factor" for that town:—

$$\text{Registrar-General's factor for the year} = \frac{\text{Recorded Death-rate of England and Wales during previous Decennium}}{\text{Standard Death-rate of the town for the year}}$$

Thus: Annual Death-rate for England and Wales from 1891–90 (inclusive) = 19.15 per 1000.

Standard Death-rate of London (1899) = 17.97 $\therefore \frac{19.15}{17.97} = 1.0656$ Factor for 1899.

Standard Death-rate of Liverpool (1899) = 17.44 $\therefore \frac{19.15}{17.44} = 1.0980$ „ „ „

Standard Death-rate of Plymouth (1899) = 19.7 $\therefore \frac{19.15}{19\ 7} = 0.9720$ „ „ „

3. The "*recorded* death-rate for the town" (*i.e.*, the *crude death-rate*) × the "factor" = "*corrected death-rate.*"

Taking the above-named cities:

Recorded (crude) Death-rate of London (1899)
= 19.78 × 1.0656 = 21.077 = "Corrected Death-rate."

„ Death-rate of Liverpool (1899)
= 26.38 × 1.098 = 28.965 = "Corrected „ „

„ Death-rate of Plymouth (1899)
= 21.72 × 0.972 = 21.111 = "Corrected „ „

Correction for Non-residents.

Deaths of Residents of the District dying in Public Institutions

are added to the Returns, (+), and those of Non-residents are subtracted (−). In private cases this is not done, as it is impracticable.

4. **The Comparative Mortality Figure.**

Recorded Death-rate of England and Wales *for the year in question* : 1000 : : corrected local death-rate : x.

i.e. $\frac{\text{Corrected local death-rate}}{\text{Death-rate for the whole country}} \times 1000 =$ Comparative Mortality Figure.

Taking the same cities as before :

Recorded Death-rate of England and Wales during 1899 = 18.33.

Corrected Death-rates as already calculated :

London : 18.33 : 1000 : : 21.077 : x = 1150. C.M. Figure, 1899.
Liverpool : „ : „ : : 28.965 : x = 1580. „ „
Plymouth : „ : „ : : 21.1 : x = 1152. „ „

Infantile Mortality is estimated on the annual number of registered deaths of children under one year of age per 1000 registered births during the same year : *not on the total population, nor on the total number of deaths* at all ages. (Still-born births are not registered.)

Formula.—Births during the year : 1000 : : Deaths of children under 1 year : x.

E.g. Births registered during the year = 2372.
Deaths „ „ „ „ under 1 year of age = 284.
2372 : 1000 : : 284 : x. 119 deaths per 1000 births = infant mortality for the year in question.

Zymotic Death-rate.—It may be for the entire group of infectious diseases or for each one in particular, and states the proportion of notified cases per 1000 of population.

E.g. Population = 21685. Deaths from diphtheria = 12.
21685 : 1000 : : 12 : x. = 0.55 per 1000 living.

Proportion of Deaths from Special Diseases to Total Deaths from all Causes.

Total deaths = 6018.
Deaths from Principal Zymotic diseases = 411.
„ „ Small-pox = 72.
6018 : 1000 : : 411 : x. 68.3 per 1000 deaths (Zymotic).
„ „ : : 72 : x. 11.9 „ „ „ (Small-pox).

Incidence of Disease.—Proportion of cases per 1000 of population.

E.g. Population = 765720. Scarlet fever cases = 2408.
765720 : 1000 : : 2408 : x = 3.14 per 1000 (= Zymotic case-rate).

Case-Mortality.—Proportion of deaths per 100, or per 1000, cases.

E.g. Of 2408 cases of scarlet fever 32 were fatal.
2408 : 100 : : 32 : x. Case-mortality = 1.3 per cent.

	Population.	Number of cases.	Incidence of Disease.
1898.	52630	241	= 4.6 per 1000 of estimated population.
1899.	54748	258	= 4.7 „ „ „ „
1900.	58676	234	= 3.9 „ „ „ „
1901.	64526	297	= 4.6 „ „ „ „
1902.	67325	340	= 5.0 „ „ „ „
	297905	1370	

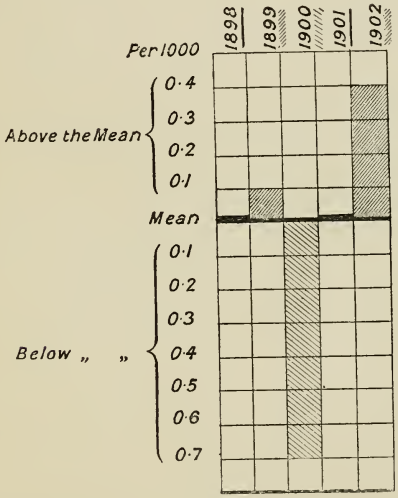

FIG. 28.

Dividing by 5 : 59581 = average pop. per ann. for 5 yrs. (by A.P.)
274 = „ no. of cases „ „
Average incidence = 4.6 per 1000 of average pop. „

During 1898 and 1901 the Incidence of Disease coincided with the average, although in 1901 there were 56 more cases than in 1898; these were counterbalanced by an increase of population.

In 1899 and 1902 it was in excess of the mean: in the first instance by 4.7—4.6 = 0.1 per 1000, or 0.01 per cent.; and in the second by 5.0—4.6 = 0.4 per 1000, or 0.04 per cent.

In 1900 there were only 7 fewer cases than in 1898, and the

proportion of attacks was 4.6—3.9 or 0.07 per cent. below the average.

Combined Death-rates.—If the populations are numerically equal, the respective rates of mortality per 1000 are added together and divided by the number of towns in question.

Three towns *each containing* 25000 inhabitants have death-rates of 22, 35, and 31.5 per 1000 respectively.

$$\text{Mean or Combined Death-rate} = \frac{22 + 35 + 31.5}{3} = 29.5 \text{ per } 1000.$$

If the populations are different their proportion to each other must be estimated:

Population 19000 at 22 deaths per 1000 = 418 deaths.
„ 22000 „ 35 „ „ „ = 770 „
„ 28000 „ 31.5 „ „ „ = 882 „

69000 : 1000 : : 2070 : x

Combined Death-rate = 30.0 per 1000.

Density of Population is important in connexion with the Death-rate of the same area, which it influences.

(1) Unit of area = 1 square mile.

Total number of square miles : 1 : : total population : x.

$$\text{Mean population per sq. mile} = \frac{\text{Population}}{\text{Square miles}}$$

Pop. = 25000. Area = 94 sq. m. $\text{Density} = \frac{25000}{94} = 266$ persons per sq. m.

(2) Unit of area = 1 acre.

Population : 1 : : total number of acres : x.

$$\text{Mean area per person} = \frac{\text{Total acres}}{\text{Population}}$$

Taking the above example: 94 sq. ms. = 94 × 640 = 60160 acres.

$$\text{Density} = \frac{60160}{2500} = 2.4 \text{ acres per person.}$$

CHAPTER XII.

LIFE-TABLES.

DATA required : 1. Census Returns to ascertain (*a*) the mean population, (*b*) numbers living at each age-period.

2. Death-returns showing : the mean annual number of deaths for the corresponding age-periods.

A. Mortality *per unit* for each year or each age-period

$$= \frac{\text{Deaths (per annum or per age-period)}}{\text{Mean population (during same period)}}$$

(In a Life-Table = "Annual Mortality" per unit at age x. "D_x" or "M_x".)

B. Mortality per 1000 living for each year or each period : Mean Popul. at age-period : 1000 : : Deaths (at same period) : x.

$$= \frac{\text{Deaths (per annum or per age-period)}}{\text{Mean population (during same period)}} \times 1000$$

Let this = D. Assuming D to be equally distributed throughout the year or age-period : Rate during 1st half-period $= \frac{D}{2}$

,, ,, 2nd ,, ,, $= \frac{D}{2}$.

∴ 1000 living (survivors) in the *middle* of the year or age-period numbered $1000 + \frac{D}{2}$ beginning ,, 1st half ,, ,, ,,

and $1000 - \frac{D}{2}$ ending ,, 2nd ,, ,, ,, ,,

∴ the "Ratio of final to initial population"

$$= \frac{\text{Survivors at the end}}{\text{Survivors at the beginning}} = \frac{1000 - \frac{D}{2}}{1000 + \frac{D}{2}} = \frac{2000 - D}{2000 + D}$$

(In Life-Tables this calculation gives the "Probability of Living one year from each age" denoted by the sign 'p_x".)

Example.—During 1st year infant mortality (per 1000 births) = 130.

1000 : 1 million : : 130 : x = 130,000 deaths.

∴ 1 million children after 1 year (at beginning of next year) = 1 million − 130,000 = 870,000 survivors at end of 1st year.

During 2nd year infant mortality = 100 (per 1000 births).

(= D of the Formula)

∴ By Formula : the probability of each survivor living through *one year* is $\frac{2000-100}{2000+100}=\frac{1900}{2100}(=0.905)$

∴ $870{,}000\times\frac{1900}{2100}=787350$ survivors at the end of the 2nd year.

(In Life-Tables found under the heading "Number born and living at each age," and denoted by l_x.)

Infant mortality = 50 per 1000 during 3rd year :

$$\frac{2000-50}{2000+50}=\frac{1950}{2050}\ (=0.9512)$$

∴ $787350\times\frac{1950}{2050}=748943$ survivors at the end of the 3rd year.

Similarly till none survive.

If instead of annual periods 5-year ones are taken (quinquennia) the method of working is similar, but the Formula is raised to the 5th power.

Let P_0 = survivors at commencement of quinquennium.

,, P_1 = ,, ,, end ,, ,,

$$P_1=P_0\times\left(\frac{2000-D}{2000+D}\right)^5$$

Example.—Of the above survivors, supposing 675,000 were living at the end of the 5th year :

And Death-rate for the 5–10 quinquennium = 6 per 1000.

Formula for *one* year = $\frac{2000-6}{2000+6}$

,, ,, 5 years = $\left(\frac{2000-6}{2000+6}\right)^5=\left(\frac{1994}{2006}\right)^5$

$= 5\times(\log 1994-\log 2006)$

$= 5\times(3.2997252-3.3023309)$

$= 5\times\bar{1}.9973943=\bar{1}.9869715=0.9704$

$675000\times0.9704=655020$ survivors.

The calculation is similarly repeated for each quinquennium until there are no survivors.

For a decennial age-period the death-rate per 1000 is $\left(\frac{2000 - D}{2000 + D}\right)^{10}$

Similarly : $P_1 = P_0 \times \left(\frac{2000 - D}{2000 + D}\right)^{10}$ (substituting decennium for quinquennium)

Expectation of Life.—The average number of years a person of a given age is likely to live *as calculated in a Life-Table.*

Expressed symbolically as "$E_x = \frac{Q_x}{l_x}$"

"Q_x = Sum of years of life lived at age x and upwards
l_x = Number of survivors at each age."

Or :

Expectation of Life at Age x

$$= \frac{\text{Sum of total survivors } \textit{after} \text{ age } x \times 5}{\text{Survivors } \textit{at} \text{ age } x} + 2.5.$$

(2.5 = Half-quinquennium).

Example.—To Calculate the Expectation of Life for Males at 40 Years of Age.

At Age	Male Survivors	
40	604923*	
45	564437	
50	517639	
55	462981	
60	398400	
65	322482	
70	238632	= 2775918
75	153890	5
80	80023	13879590
85	29866	
90	6786	
95	752	
100	30	

$$\frac{13879590}{604923} + 2.5 = 22.94 + 2.5 = 25.44 \text{ years.}$$

* Tatham's *English Life-Tables* (1881–90).

For a Female-life at the same age:

At Age	Female Survivors	
40	638912	
45	604007	
50	564299	
55	516375	
60	457682	
65	385503	
70	299220	3209632×5
75	204208	$= 16048160$
80	114536	
85	48133	
90	13418	
95	2124	
100	157	

$$\frac{16048160}{638912} + 2.5 = 25.11 + 2.5 = 27.61 \text{ years.}$$

In the above Examples 22.94 and 25.11 are known as the "Curtate Expectation of Life;" and 2.5 as the "Duration of Life in the Quinquennium of Death" (= half a quinquennium or $2\frac{1}{2}$ years). These added together give the "Complete Expectation of Life," as stated in Life-Tables under the heading "Mean after Lifetime at each age $x = E_x$." In Tables giving Annual, and not Quinquennial age-periods, the number of survivors is added as above (the result is *not* multiplied by 5) to obtain the Curtate Expectation, and 0.5 is added (in place of 2.5) to get the Complete Expectation of Life.

"Mean Duration of Life" = The Expectation of Life at Birth, or at "Age zero."

By **Farr's Formula,** the expectation of life at birth per 1000 living:

$$= \frac{1}{3} \times \frac{1000}{\text{Birth-rate}} + \frac{2}{3} \times \frac{1000}{\text{Death-rate}}$$

EXAMPLE.—Birth-rate per 1000 living = 30.5

Death- „ „ „ „ = 17.3

$$\frac{1000}{3 \times 30.5} + \frac{2000}{3 \times 17.3} = \frac{1000}{91.5} + \frac{2000}{51.9} = 10.93 + 38.53$$

$$= 49.46 \text{ years.}$$

"Mean after lifetime": the expectation of life at any *later* age than at birth.

By **Willich's Formula:** the expectation of life at *any age between* 25 *and* 75 *years* $= \frac{2}{3}\left(80 - \text{Age}\right)$.

EXAMPLE.—Expectation of life at $45 = \frac{2}{3}\left(80 - 45\right)$.
$= 23.3$ years.

"Probable Duration of Life": the age at which half a given number of children (born hypothetically at the same time) will have died.

"Mean Age at Death": $\frac{\text{Sum of the Ages at Death}}{\text{Number of Deaths}}$

Poisson's Formula for estimating the liability to error.

1st series of observations $= m$ \
2nd ,, ,, ,, $= n$ / $m + n = \mu =$ Total number of observations.

Probability of m series being constant $= \frac{m}{\mu}$

,, ,, n ,, ,, ,, $= \frac{n}{\mu}$

True proportion of m to μ lies between: $\frac{m}{\mu} \pm 2\sqrt{\frac{2mn}{\mu^3}}$

i.e., within a possible range of $4\sqrt{\frac{2mn}{\mu^3}}$
$= \sqrt{\frac{32mn}{\mu^3}}$

Similarly for the n series the true proportion of n to μ lies between $\frac{n}{\mu} \pm \sqrt{\frac{32mn}{\mu^3}}$.

EXAMPLE.—Of 500 cases, 425 recovered and 75 died.

Probability of recovery $= \frac{425}{500} = 85$ per cent.

,, ,, death $= \frac{75}{500} = 15$,, ,,

Possible *range* of error $= \sqrt{\frac{32 \times 425 \times 85}{(500)^3}}$.
$= \sqrt{\frac{32 \times 17 \times 17}{100 \times 100 \times 100}} = \frac{\sqrt{38.08}}{1000}$.
$= \frac{9.62}{100}$ or 9.62 per cent.

$\therefore$ Probability of recovery varies between $85 \pm \frac{9.62}{2}$
or ,, 89.81 and 80.19 per cent.

,, ,, death ,, ,, $15 \pm \frac{9.62}{2}$
,, ,, 19.8 and 10.2 ,,

APPENDIX

Humidity (p. 32).

EXAMPLE.—Relative humidity at 60° F. = 70 per cent.
By Tables: 60° F. = 5.8 grains per cubic ft. of aqueous vapour.
Absolute humidity: 100 : 70 : : 5.8 : $x = 4.06$ grains per cb. ft.
Drying-power: $5.8 - 4.06 = 1.74$ „ „ „

Case-Mortality (p. 137).

EXAMPLE.—A Hospital contains 500 beds, $\frac{3}{4}$ of which are constantly occupied.

Average period in Hospital per patient = 3 weeks.
„ number of deaths per annum = 142.

Supposing the cases to be uniformly distributed over the whole-period, what is:

(*a*) the death-rate per bed,
(*b*) „ „ „ 100 cases admitted?

Beds constantly occupied = $\frac{3}{4}$ of 500 = 375.

Death-rate per bed „ $= \frac{142}{375} = 0.38$.

As each case remains 3 weeks, in one year there are:

$$\frac{52}{3} = 17.3 \text{ patients per bed.}$$

$375 \times 17.3 = 6487$ cases admitted, of which 142 die.
$\therefore$ 6487 : 100 : : 142 : $x = 2.2$ deaths per cent. of admissions.

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